ABSTRACT

OPTIMIZING RAIL-TRUCK INTERMODAL DRAYAGE OPERATIONS

by
Wen Zhang

This thesis presents a case study of the trucking (or drayage) portion of rail-truck intermodal freight transportation. The approach used was to examine in detail the current costs and potential for improvement at one New Jersey intermodal terminal. The analysis is conducted using a mathematical programming model to find an optimal scheduling plan for the drayage operation. To solve the model more efficiently, a modification is made to explore the special structure of the original problem which has a sparse constraint matrix. The model is solved first with an objective function that minimizes the total cost of the operation, and then with an objective function that minimizes the total tractor fleet size required to move the containers. The model results indicate a 19.2% and 52.7% reduction in overall costs respectively for the objectives of minimizing total cost and minimizing fleet size. This reduction is achieved by repositioning and reloading containers, after they have been unloaded at consignees.

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by
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This thesis is dedicated to
my friends and family
who have supported me throughout this work

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TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

CHAPTER 1

INTRODUCTION

This thesis presents a mathematical programming technique which optimizes delivery, repositioning and pickup operations of containers in rail-truck intermodal freight transport, and examines the service quality and efficiency of the operations. In intermodal transport, a load is moved between an origin and a destination in the same container in a coordinated manner using two or more transportation modes. The specific system of concern in this thesis is that used in conjunction with rail-truck intermodal freight transportation in the United States. In this system, highway trailers or containers are loaded on rail flat cars and hauled by train in line-haul service between the origin and destination rail terminals, and locally picked up and delivered by truck between the rail terminal and shippers and receivers (termed consignees). The highway portion of the intermodal rail-truck service is called drayage.

The basic concept of rail-truck drayage service starts with the dispatch of a tractor with an empty container from the rail terminal to the shipper. The tractor can wait while the container is loaded and, upon loading, return it to the terminal for an outbound rail movement. This procedure is called "stay with". Alternatively, the tractors can deliver an empty container to the shipper, leave it there and depart for another assignment. The same tractor (or a different one) returns to the shipper to pick up the loaded container and deliver it to the rail terminal. This procedure is called "drop and pick". At the destination terminal, the loaded containers are delivered to consignees by truck either the "stay with" or "drop and pick" procedure.

1.1 Historical Trends

Intermodal rail-truck or, as it is popularly refereed to, piggyback service is a very old concept. It began as early as 1926 when Chicago North Shore and Milwaukee Railroad used their own containers, carried on specially designed flat cars to transport merchandise between Chicago and Milwaukee (Mahoney, 1985). Intermodal rail-truck service is a competitive alternative to over-the-road trucking because it provides shippers with a door-to-door service that is attractive in terms of price and service quality. Its main advantage is that it combines the best of two modes: the low cost of rail in line-haul and the flexibility of truck in local pick-up and delivery. In spite of its advantages, piggyback did not experience a substantial increase in traffic volume for many years (Morlok et al., 1994). The first reason for the underdevelopment of the service was the government regulation. Between 1930 and 1980, the Interstate Commerce Commission's (ICC) decision in 1931 that railroads could use only the traditional high rail class (commodity-based) rates, instead of flat piggyback rates, for the movement of merchandise freight in piggyback service, prevented railroads from competing with truckers. This decision, along with other restrictions weakened the railroads competitive position against truckers. The second reason was the railroads' reluctance to invest their capital on development, operation and marketing of intermodal services because they thought they would not be as profitable as box car service. As it turned out, this was very much incorrect. The third reason was the lack of innovations in intermodal technology and train operations in piggyback service which caused the decrease in service quality and increase in freight damage.

1.2 Current Situations

In the last few years, both traffic volume and the market share of intermodal transport has increased significantly over the 1980's. In the last decade, intermodal service as a whole has grown by a factor of over 100%, (from 3.06 million units in 1980 to 6.21 million units in 1990) (Association of American Railroads, 1992). Intermodal market share in freight transport has increased from 10% in the 1980's to 20% of 1993 (Intermodal Association of North America, 1993).

It is widely thought that this increase in traffic volume was caused by several major changes in the regulatory environment, traffic flow patterns, and technology:

- Railroad deregulation introduced in the Staggers Rail Act of 1980 gave the railroads the freedom to set their own intermodal rates, which, in turn, enabled them to offer lower rates than truckers. The act also gave railroads contracting freedoms, enabling them to serve large volume shippers better. Railroads rely on third parties, or volume shippers, called Intermodal Marketing Companies to provide door to door service and compete with truckers.
- The changing trade patterns that occurred in the 1980's when Pacific Rim countries became the main trading partners of the US, resulted in large amounts of freight being imported to the US. A large portion of that cargo was unloaded on the West Coast and moved inland by rail.

- Technological innovation in intermodal transport improved service quality and increased equipment productivity. These innovations included, the introduction of unit trains that moved between the origin and destination terminal without going through classification yards, modernization of the terminal handling equipment that increased terminal productivity, new locomotive and flat car designs that reduced jerk forces and thus banging and cargo damage while at the same time resulted in lighter trains that are more fuel efficient.
- The shortage of qualified long haul drivers resulted in several interesting partnership between railroads and over-the-road truckers, the most notable of which is the partnership between J. B. Hunt and Santa Fe Railroad. J. B. Hunt kept its drayage operations in major markets and contracted out the line-haul portion to the Santa Fe. It is also interesting to note that several truckers such as Schneider National have followed the example set by J.B. Hunt in establishing strategic partnerships with railroads. They also invested their capital to buy intermodal containers that are much sturdier than highway trailers. For example, J. B. Hunt invested 56 million dollars in new containers that are used exclusively in intermodal (Morlok and Spasovic, 1994).

1.3 Problems

Presently, intermodal rail-truck service accounts for about 20% of the intercity merchandise cargo that is moving over 500 miles. Given that the majority of freight moves over distances of 500 miles or less (US Department of Transportation, 1990), the intermodal must improve its competitiveness if it were to capture the larger share of market.

The main factor which prevents intermodal rail-truck service from gaining larger market share is its relatively high fixed cost when compared with trucks. The fixed cost of trucking is $80 to $120 per load, while the variable cost ranges between $1.00 and $ 1.50 per loaded truck-mile. The fixed cost for intermodal rail-truck service is higher than that of trucking because it has to include the cost of providing terminal facilities, loading containers on rail cars, and delivering or picking up containers. Typically, the fixed cost of intermodal is $300 to $500 per load. But, its distance based rail-line haul cost is lower than that of trucking, varying between $0.60 and $0.80 per loaded mile. Figure 1.1 shows the cost characteristics of intermodal rail-truck service and over-the-road trucking. Due to the different cost structure, there is a break-even point at which the cost of intermodal is equal that of intercity trucking. Choosing the mid-range values for costs, the break-even distance is 545 miles. This is in agreement with the current belief that this distance is in a range of 500 to 700 miles.

The preceding discussion has been in terms of carrier cost only. It is also important to consider the cost incurred by the shipper. The shipper not only pays the carrier directly for the transportation service, but in addition incurs other costs associated with the movement (i.e., the inventory cost of the cargo while in transit, inventory used as a safety stock in case expected deliveries are late, etc.) It is currently estimated that when these costs are included, the break-even distance is in a 700 to 1,000 mile range. Using the costs of over-the-road and intermodal movements, and including a penalty of 15% added to the intermodal carrier's costs to adjust for service inferiority, results in a break-even distance of 809 miles.

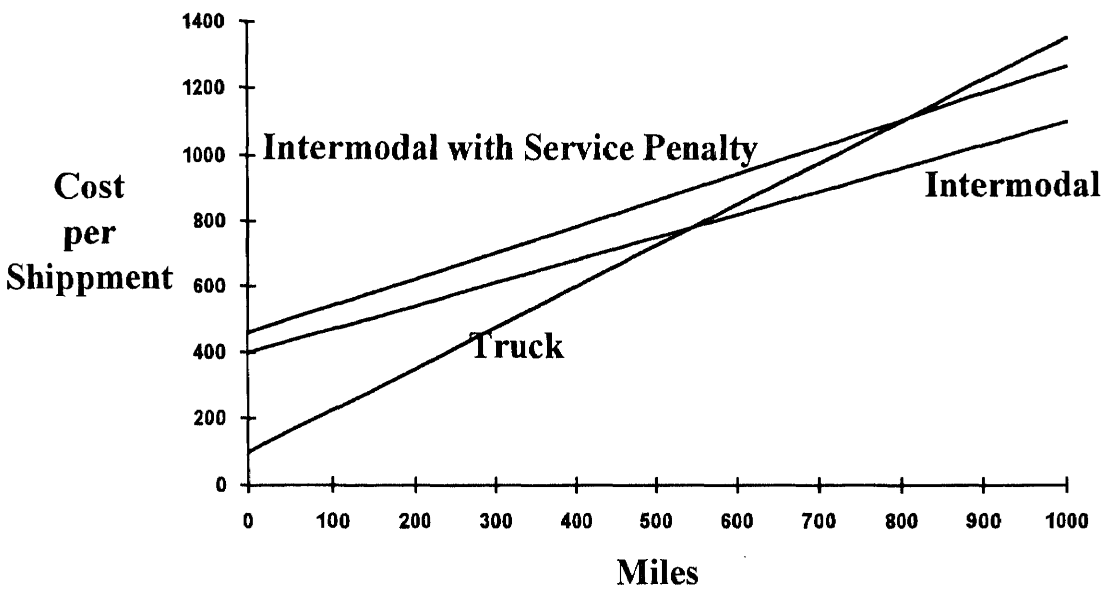


Figure 1.1 Costs, including Shippers' Costs, of Current Piggyback and Intercity Trucking.
Source: Morlok et al. 1994.

Clearly, reducing the fixed cost of intermodal would enable the two lines to intersect at shorter distances making intermodal more competitive with trucking at shorter distances.

Certain parts of fixed cost were already reduced by the end of the 80's when technological innovations were introduced. These new technologies included new, efficient loading equipment, which reduced the loading time at terminals and thereby increased productivity. Also, the use of unit trains reduced the extra handling time at intermediate classification yards, thus decreasing related delays. In spite of the above improvements, the fixed cost of the highway portion, or drayage, remained high. Therefore, the main focus of this study is to explore ways to reduce drayage cost.

Chapter 2 of this thesis introduces the study approach used to examine the potential of reducing the cost and improving the quality of intermodal services. Chapter 3 describes the model used in this study, and the solution approach. Chapter 4 presents a case study of an intermodal drayage operation, to which the model is applied. Chapter 5 presents the results of the case study, and chapter 6 presents the conclusions and suggestions for future research.

CHAPTER 2

STUDY APPROACH

The study approach shown in Figure 2.1 begins by collecting traffic data (shipper/consignee loads) and cost (rates, etc.) data which are then put in a proper format so that the cost of the current operation can be calculated. The data are entered into an optimization model, and optimized drayage schedules that satisfy given service quality constraints are generated. The total cost of the optimized drayage plans is then compared with the current cost to assess potential savings.

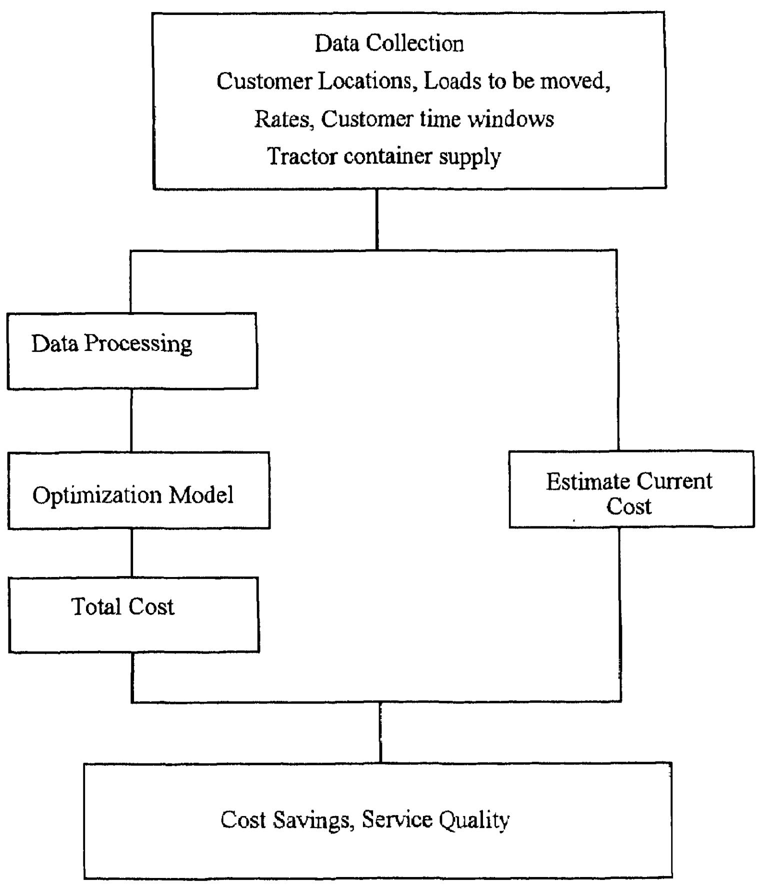


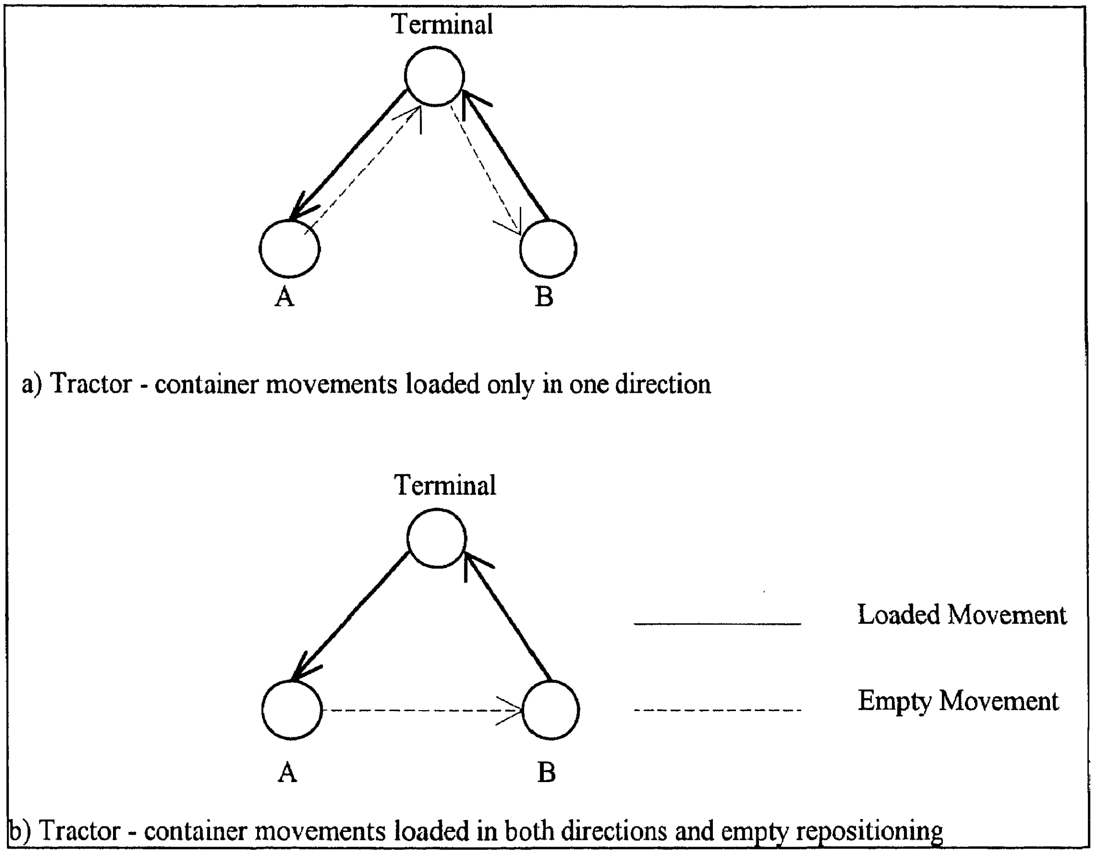
Figure 2.1 Study Approach

2.1 Current vs Centralized Drayage Operation

Current drayage operations are costly. This high cost is associated with the high percentage of tractor and tractor-container non-revenue movements that are required to achieve a high level of service of pick ups and deliveries. These non-revenue movements are termed deadheading (when a tractor moves an empty container), and bobtailing (when a tractor travels without a container). This inefficiency is also a result of the absence of complete information about empty container locations and movement needs, because the control over drayage is fragmented between the various agents in intermodal service (i.e., Intermodal Marketing Companies who arrange for the movement, railroads, and drayage truckers).

Often a load is delivered to a consignee and upon unloading it is returned to the terminal, while at the same time an empty container is taken out of the terminal and delivered to a shipper in the consignee's vicinity for loading. Figure 2.2 (a) shows this operating procedure. It is clear that if the operation is centralized, the drayage operating cost can be greatly reduced by combining the delivery at the consignee with a pick-up at the shipper, as shown in Figure 2.2 (b). In this particular case, the drayage provider can reposition an empty container from the consignee (at location A) to the shipper (at location B) to pick up a load instead of sending it to the terminal. In general, with centralized control and information sharing, cases of two round trip movements, each loaded in one direction, could be replaced with one round trip movement with loads in both directions. The cost of this operation would obviously be lower.

In the centralized operation, it is envisioned that the drayage provider has complete information about shipper/consignee demand at each location. Therefore, it is possible to match different loads to reduce bobtailing and deadheading, and thus cost. This reduction in cost would lead toward improved profitability of service and make intermodal freight transportation more competitive. To assess the potential savings, a model (Spasovic, 1990) was applied to a real-world case of drayage operations.



a) Tractor - container movements loaded only in one direction

b) Tractor - container movements loaded in both directions and empty repositioning

Figure 2.2 Savings Resulting from Tractor-Container Repositioning.
Source: Spasovic. "Planning Intermodal Drayage Network Operations". 1990. pp. 137.

2.2 Pricing

It is important to note that in the current operation the cost of drayage is derived by assuming that a driver will haul a load only in one direction for each terminal to consignee/shipper and back movement. There are two types of rates, one for each operating procedure: stay with and drop and pick. In the stay with procedure, a tractor stays with the container while it is unloaded (or loaded). Thus, this rate includes some amount, usually two hours, of tractor idle time. In the drop and pick procedure, the driver leaves the container and departs for another assignment. A tractor returns at a later time to pick up the container. Thus, this rate must include a substantial amount of empty miles. It is clear that in the current payment schemes, the rates must be set at a high level to offset non revenue movements such as tractor idling, bobtailing and deadheading. It is usually assumed that the stay-with rate includes 50% of non-revenue miles, while the drop and pick can include up to 75% of non-revenue miles.

In the centralized operation, the schedules are developed for the whole service area, thus there is an opportunity to reduce non-revenue movements, thereby reducing operating cost. In this operation, a more efficient payment scheme can be adopted wherein the driver is paid on a piece-work basis (i.e., individually for each activity such as to deliver a load, reposition an empty container, etc.). The rates obviously could include tractor idling, bobtailing and deadheading or all of them. A more efficient payment scheme could be to lease drivers and tractors for a certain period. It was shown that this alternative further reduced drayage costs (Spasovic, 1990).

CHAPTER 3

MODEL OF DRAYAGE OPERATIONS

This chapter describes a model of drayage operations in rail-truck intermodal transport. A detailed description of the model used can be found in Spasovic (1990). The model is used to give planners a tool with which they can obtain optimized schedules for tractor-container operations, analyze alternative designs of the drayage system and answer questions related to service quality and efficiency of each alternative. Typical questions which the model could answer are:

- What is the total cost of each of these alternatives?
- What is the advantage of a centralized operation? Can any savings be expected if the operation is centralized, and if the answer is affirmative, what is the magnitude of the savings?

3.1 Notation

The model is a time space model in which variables (tractor and container activities) are modeled in a three dimensional space. The three dimensional space describes a vehicle's activity at or between two locations during a particular time period. Let (x, y) represent a consignee/shipper location, and t represent the time at which the vehicle begins its movement. Then, the three dimensional space (x, y, t) can completely describes a tractor or container activity. The model tracks the movement of a vehicle through time by dividing the analysis period into equal fixed time intervals. The letter T is used to designate both the fixed moments in time and the time period $[T-1, T]$. The planning horizon is represented as a set $\tau = [0, 1, 2, \ldots T, \ldots D*P]$, where D is a number of days and P is the number of periods per day. To track each tractor-container activity at different time periods, the following activity times are also used:

T^f_{JM} = time required for a loaded tractor- container movement from area J to area M

T^e_{JM} = time required for an empty tractor-container movement from J to M

T^b_{JM} = time of bobtailing tractor movement from J to M

TL_J = time required for loading a container at J

TU_J = time required for unloading container at J

Since the distances between the terminal and a consignee/shipper, as well as among consignees/shippers, are different, the activity times required to complete a movement to and from different locations is also different. Since the tractors are not allowed to stay at locations overnight, the model must also make sure that all tractors return to the terminal by the end of the day. Two concepts, 1. feasible departures from areas, and 2. accessibility of areas, ensure this.

Feasible departures are ensured by defining the following set:

ψ_{JM} = set of feasible tractor or tractor-container departure moments from J to M.

This set excludes departures to locations from which the tractors could not return to the terminal before the end of a day. It also ensures that for each location, the first activity out of a consignee/shipper can occur only after a tractor has arrived that area at the beginning of each day.

The accessibility of areas determines, for each area and time at which a vehicle arrives at the area, a set of departure times and set of areas from which the vehicle could have departed.

The following notation is used:

α_{JT} = set of area-time departure points for tractors of loaded tractor-containers that arrive at J at T.

γ_{JT} = set of area-time departure points for tractors of empty tractor-containers that arrive at J at T.

β_{JT} = set of area-time departure points for bobtailing tractors that arrive at J at T.

δ_{JT} = set of terminal -time departure points for loaded containers that arrive at J at T.

ω_{OT} = set of area-time departure points for loaded containers that begin their activity to terminal O at T.

These sets must be developed carefully to ensure that all the flows in the model solution are physically realizable.

3.1.1 Choice Variables

The choice variables designate integer flows of tractors and tractors with containers. The first subscript of a variable represents the origin, the second subscript represents the destination and the third subscript represents time. Superscripts are used to indicate the moments when the loads are available for delivery at the terminal, or pick up at a shipper.

f^{R}_{OJT} = flow of loaded tractor-containers available for delivery at R from terminal O to J departing at T.

f^{R}_{JOT} = flow of loaded tractor-containers available for pick up at R from J to terminal O departing at T.

e_{OJT} = flow of empty tractor-containers from terminal O to J at T.

e_{JOT} = flow of empty tractor-containers from J to terminal O at T.

r_{JMT} = flow of empty tractor-containers from area J to area M at T.

b_{OJT} = flow of bobtailing tractors from terminal O to J at T.

b_{JOT} = flow of bobtailing tractors from J to terminal O at T.

b_{JMT} = flow of bobtailing tractors from J to M at T.

b_{JJT} = flow of tractors idling at J beginning at T [i.e., during the time interval (T, $T+1$)].

h_{OT} = tractors remaining idle at terminal O beginning at T [i.e., during the time interval (T, $T+1$)].

ee_{JT} = containers staying at J after T [i.e., during the time interval (T, $T+1$)].

3.1.2 Costs Associated with Tractor and Tractor-Container Activities

Certain costs are related to the tractor and tractor-container activity in the drayage operation. The following costs are incorporated:

- The cost of moving loaded or empty containers, and tractor bobtailing. The model can accept various cost structures, either as rates for individual movements or a unit price ($/mile) multiplied by distance.
- The cost of tractor idling at consignee/shipper's location, which is usually a function of time.

3.2 Mathematical Formulation

The model of drayage operations is formulated as an integer program with a linear objective function and linear constraints. The objective function is the total operating cost of all tractor-container movements and tractor bobtailing. The choice variables representing these movements are f^R_{OJT}, f^R_{JOT}, e_{OJT}, e_{JOT}, r_{JMT}, b_{OJT}, b_{JMT}, b_{JJT}. The costs associated with these variables are:

1. the cost of delivering loaded containers from and to the terminal, C_{ojt}, C_{jot}
2. the cost of delivering empty containers to and from the terminal, K_{ojt}, K_{jot}
3. the cost of repositioning empty containers from consignees to shippers, K_{jmt}, K_{mjt}
4. the cost of bobtailing the tractors from and to the terminal, q_{ojt}, q_{jot} and
5. the cost of bobtailing the tractors form one consignee/shipper to another, q_{jmt}, q_{mjt}.

The complete mathematical formulation, with the objective function of minimization of cost based on individual movements (i.e., piece work pricing) is shown in Table 3.1. Constraint 1 specifies that all the loads available at the terminal at certain time (i.e., R) must be delivered to a consignee within the specified time window (i.e., [R, $R+MP$]). Constraint 2 specifies that all the loads available at certain time at the shippers must be picked up within the specified time window. Constraint 3 ensures that the flow of tractors is conserved at each area J and time T. Constraint 4 ensures that the flow of containers is conserved at each area J and time T.

Table 3.1 Model of Drayage Operation with Piece work Pricing

Min z $= \sum_{J\in\xi}\sum_{T\in\tau}\sum_{R} C_{OJT} * (f^{R}_{OJT} + f^{R}_{JOT}) + \sum_{J\in\xi}\sum_{T\in\tau} k_{OJT} * (e_{JOT} + e_{OJT}) + \sum_{J\in\xi}\sum_{T\in\tau}\sum_{M\in\xi} k_{JMT} * r_{JMT}$

$+ \sum_{J\in\xi}\sum_{T\in\tau} q_{OJT} * (b_{OJT} + b_{JOT}) + \sum_{J\in\xi}\sum_{T\in\tau}\sum_{M\in\xi} q_{JMT} * b_{JMT}$

subject to:

Constraint 1. Service Quality of Container Load Deliveries to Areas

$\sum_{M=1}^{M=G}\sum_{T=R}^{R+MP} f^{R}_{OJT} = C^{R}_{J}$ $\forall$ J, R and for specified P (i.e., $P=Q$) and M (i.e., $M=G$)

Constraint 2. Service Quality of Container Load Pick Ups at Areas

$\sum_{N=1}^{N=I}\sum_{T=R}^{R+NP} f^{R}_{JOT} = S^{R}_{J}$ $\forall J, R$ and for specified P (i.e., $P=Q$) and N (i.e., $N=I$)

Constraint 3 . Tractor Flow Conservation

$\sum_{OV\in\beta_{JT}} b_{OJV} + \sum_{MV\in\beta_{JT}} b_{MJV} + \sum_{OV\in\alpha_{JT}}\sum_{R\le T} f^{R}_{OJV} + \sum_{OV\in\gamma_{JT}} e_{OJV} - e_{JOT} - \sum_{M\in\xi} r_{JMT} - b_{JOT} - \sum_{M\in\xi} b_{JMT} - \sum_{R\le T} f^{R}_{JOT} = 0 \quad \forall T,J$

Constraint 4. Container Flow Conservation

$ee_{JT-1} + \sum_{OV\in\sigma_{JT}}\sum_{R\le T} f^{R}_{OJV} + \sum_{OV\in\gamma_{JT}} e_{OJV} + \sum_{MV\in\gamma_{JT}} r_{MJV} - e_{JOT} - \sum_{M\in\xi} r_{JMT} - \sum_{JV\in\omega_{OT}}\sum_{R\le T} f^{R}_{JOV} - ee_{JT} = 0 \quad \forall T,J$

Constraint 5. Non-negativity and integrality

All f^{R}_{OJT}, f^{R}_{JOT}, e_{OJT}, e_{JOT}, r_{JMT}, b_{JOT}, b_{OJT}, b_{JMT}, ee_{JT} $\ge$ 0 and integer.

Source: Spasovic. 1990. “Planning Intermodal Drayage Network Operations.” pp. 98.

3.3 Solution Approach

In general, integer linear programs are difficult to solve and require a substantial computational effort. A method, called Multi-Stage procedure, was developed to solve the model. The method uses a heuristic to round real valued solutions that are obtained by solving a sequence of linear programs with a near network structure to integer solutions. The network structure enables the integer programs to be solved very efficiently by using a LP algorithm to yield integer solutions.

Spasovic (Spasovic, 1990) shows that when the following three redundant constraints are added to the model, the model's structure becomes near network:

Constraint 6. Restriction on Magnitude of Tractor-Container Deadheading from Terminal to Areas.

$$\sum_{J \in \xi} \sum_{T \in \tau} e_{OJT} \leq \sum_{R} S_J^R$$

Constraint 7. Restriction on Magnitude of Tractor-Container Deadheading from Areas to Terminal.

$$\sum_{J \in \xi} \sum_{T \in \tau} e_{JOT} \leq \sum_{R} C_J^R$$

Constraint 8. Restriction on Magnitude of Tractor Bobtailing between Terminal and Areas.

$$\sum_{J \in \xi} \sum_{T \in \tau} b_{OJT} = \sum_{J \in \xi} \sum_{T \in \tau} b_{JOT}$$

This solution procedure explores the near network structure of the problem, designated as $P_{i,}$ and uses a heuristic method to reach an integer feasible solution. The procedure starts with the solution to the relaxed LP program which provides a lower bound for P_i. The relaxed problem is solved first and the variables are carefully made integers.

The multi stage procedure is presented as an algorithm:

Step 1: For the problem P_i, add redundant constraints (constraint 6, 7 and 8), and replace intergrality constraints with non-negativity constraints. Solve the problem as a LP. Round loaded tractor-container variables f^R_{OJT} and f^R_{JOT}. Verify that the rounding does not violate the service quality constraints.

Step 2: Using rounded tractor-container variables as input to the problem, solve the model as a LP. If all the decision variables are integer, then stop, since an integer feasible solution has been found. Otherwise, round the empty tractor-container variables.

Step 3: Fix all the rounded loaded and empty tractor-container decision variables and solve the model as a LP. All the tractor and idling container variables should be integer because of the network structure.

3.4 Alternative Objective Function

Another alternative objective function is the minimization of total tractor fleet size. This objective function is associated with the operating procedure of direct leasing of tractors for consecutive days. The problem is to determine the optimum number of tractors required to move loaded and empty containers. In addition, the following constraints are added to the model formulation. The choice variables are the same as before, but a new variable ***fleet*** is added to the model.

Constraint 9 Tractor flow conservation at the terminal

$$-\sum_{R\le T} f^{R}_{JOT} - e_{JOT} - b_{JOT} - b_{OOT-1} - fleet_{t=\text{end period}} + fleet_{t=0} + \sum_{OV\in\alpha_{JT}} \sum_{R\le T} f_{OJV} + \sum_{OV\in\gamma_{JT}} e_{OJV} = 0$$

Constraint 10 Restriction on bobtail movement when $M \notin \beta_{JT}$

$$\sum_{J\in\xi} \sum_{MV\notin\beta_{JT}} b_{MJV} = 0$$

Constraint 11 Restriction on empty movement when $M \notin \gamma_{JT}$

$$\sum_{J\in\xi} \sum_{MV\notin\gamma_{JT}} e_{MJV} = 0$$

The objective function is formulated as follows:

$$\lambda_1 * fleet + \lambda_2 * (\sum_{J\in\xi} \sum_{T\in\tau} (b_{OJT} + b_{JOT}) + \sum_{J\in\xi} \sum_{T\in\tau} (e_{OJT} + e_{JOT}) + \sum_{J\in\xi} \sum_{V\in\gamma_{JT}} e_{MJV} + \sum_{J\in\xi} \sum_{V\in\beta_{JT}} b_{MJV})$$

However, this problem formulation has specific features when implementing an optimization program. Constraints 10 and 11 are added to prevent the model of generating unnecessary non-revenue (i.e., bobtail and deadheading) movements. This problem does not exists in the model that minimizes total operating cost since each bobtail and deadheading movement has a positive marginal cost associated with it. If these constraints are not added to the model the solver may generate those non-revenue movements that make no contribution to satisfying delivery and pickup constraints and can enlarge actual fleet size without registering this increase in the variable ***fleet***, which designates the fleet size. This problem can be also solved using the Multi-Stage procedure.

CHAPTER 4

CASE STUDY

To apply the model presented in the previous chapter, a comprehensive data collection effort was undertaken at an intermodal terminal in South Kearny, New Jersey during the period of April, 25, 1994 to May, 15, 1994. The data included locations of shippers and consignees, traffic volumes (or demand) of loads to be moved, and costs. Within the study, two different payment plans were evaluated. One is the payment on per load basis, while the other is leasing tractors for a certain time period. The study also included an analysis of possible savings of a centralized operation over independent separate operations. This chapter begins with a performance evaluation of the current drayage operations. Then, a case study of the drayage system to which the model was applied is presented.

4.1 Performance Evaluation of Current Drayage Operations

In drayage operations, the service quality is directly related to the time that is elapsed from the arrival of a loaded container by rail until it is delivered to the consignee by truck (or from the time of request by the shipper of an empty container to be delivered by truck until it is delivered loaded to the rail terminal). In the *1993 Intermodal Index*, quality of delivery and quality of pickup rank 1 and 3 as the main criteria of performance ratings. In terms of customer service attributes, on-time delivery and on-time pickup is the main factor affecting quality of delivery and pickup operations.

To evaluate the performance of drayage operations, two measure of effectiveness are developed:

- the mean and standard deviation of the time between the arrival of loads to the terminal by rail and their scheduled delivery to the consignee.
- the mean and standard deviation of the time between the actual delivery by truck to the consignee and the scheduled arrival.

These measures represent good indicators of the responsiveness of drayage companies.

The average time between the arrival by rail and scheduled delivery of a loaded container to a consignee by truck was 2.328 days, with a standard deviation of 1.795 days. The sample size was 137 load deliveries. Figure 4.1 shows the distribution of days between arrival by rail and the scheduled delivery by truck.

The average time between the actual and scheduled delivery of a loaded container to a consignee is -4.16 minutes, with a standard deviation of 23.36 minutes. The sample size was 131 load deliveries. Figure 4.2 show the distribution of minutes between the actual and scheduled delivery arrival by truck.

4.2 Case Study Description and Data Requirements

The case study requires the following data which are classified in three categories.

I. Spatial Data

- spatial distribution of origins and destinations for containers in the terminal service

CHAPTER 2

STUDY APPROACH

The study approach shown in Figure 2.1 begins by collecting traffic data (shipper/consignee loads) and cost (rates, etc.) data which are then put in a proper format so that the cost of the current operation can be calculated. The data are entered into an optimization model, and optimized drayage schedules that satisfy given service quality constraints are generated. The total cost of the optimized drayage plans is then compared with the current cost to assess potential savings.

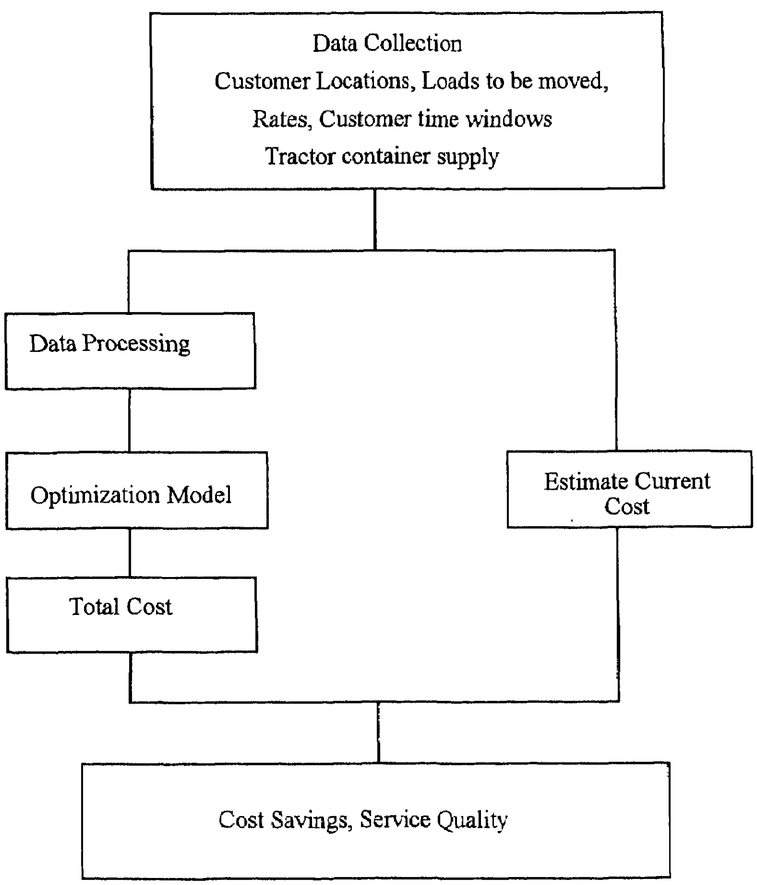


Figure 2.1 Study Approach

- travel time and distance among different shipper/consignee locations.

II. Demand data

- demand for delivery of loaded containers at consignees (including the times they are available for delivery).
- demand for pick up of container at shippers (including the times when they are available for pick up)

III. Cost data

- cost of loaded and empty movements of tractor-containers,
- cost of tractor bobtailing and idling,
- lease rates.

The data of this case study were extracted form four sources.

- a Northeastern railroad train arrival time sheets
- a drayage company dispatch sheets
- a Midwestern railroad (that turned over the containers to the Northeastern railroad) container service daily operating log
- a Midwestern railroad container service drayage rate sheets

The information extracted from these sources included container number, consignee/shipper's addresses, zip codes, notification dates (the time when an arriving-by-rail container is available to be delivered or picked up), scheduled dates (the time when a container is scheduled to be delivered or picked up), one way distances from each consignee/shipper to the terminal and rates charged.

4.3 Alternatives Drayage Operating Plans

In addition to the present operation, a baseline to which alternative operating plans can be compared, two alternative plans that have the potential of reducing cost, and improving efficiency of drayage have been identified.

Alternative 1: Baseline

This alternative reflects the current operation in which drayers are paid for a one-way loaded terminal-to-consignee/shipper round trip movement. The trip can consist of delivering a loaded container to a consignee and returning it empty or delivering an empty container to a shipper and bringing it back loaded. The baseline cost for the total operation is given as the total rates the drayage provider charged for actual movements of loads between the terminal and customers.

Alternative 2: Centralized Drayage Operations Planning with Piece-Work Pricing

This plan is based on the assumption that the drayage provider has complete information on shipper and consignee demand in the entire terminal service area. Unlike the baseline situation in which the tractors have to return to the terminal before they can be dispatched for another assignment, this plan permits a tractor to move directly from one assignment to the next. The procedure usually combines two round trip movements with 50% empty miles into two loaded movements with empty repositioning. Four payment plan are conceived:

Plan A: the drayer is paid for one way loaded movements, one way empty movements between areas and the terminal, and tractor idling between assignments.

Plan B: In addition to Plan A, this plan includes the payment for empty repositioning between areas.

Plan C: In addition to Plan B, this plan includes the payment for tractor bobtailing between areas.

Plan D: The drayer is paid on an hourly (as opposed to mileage) basis.

Alternative 3: Centralized Drayage Operations Planning with Direct Tractor Leasing

This alternative involve leasing a certain number of tractors and drivers for a certain time period.

4.4 Data Processing

The data collection resulted in a total of 294 container loads; 253 loads to be delivered from the terminal to consignees, and 41 loads to be picked up from shippers. Some of the loads had incomplete information, with location and time information missing, while some of them had arrived before the study period and were scheduled to be delivered during the study period. Among the 253 consignee loads:

- 27 have arrival (notification) date before the study period
- 6 have notification date after the study period
- 4 have notification dates missing
- 94 have scheduled dates and times missing
- 8 have scheduled delivery date after the end of study period

Among the 41 shipper loads:

- 3 arrived (notification date) before the study period

- 24 have notification dates missing
- 1 has a scheduled pick up date before the study period.

The missing notification and scheduled information was filled in by using the average data from the complete shippers records. For example, the notification date for a pick up was estimated by subtracting the mean time between the scheduled date and the notification date from its scheduled date. The resulting sample of container load movements, by zip code is show in Appendix A.

4.4.1 Data Base Aggregation

The model of drayage operations considers container movements between the areas. Each area consists of several shippers/consignees in proximity to each other. The 253 shippers and consignees were aggregated by zip code into 40 areas shown in Figures 4.3 and 4.4. The composition of each area is also shown in Appendix B.

The aggregation was done with the AUTOMAP software (Atherton A. et. al. 1991). AUTOMAP allows the user to select a specific location point on a map and measure the distance from this location to any other location. The distances calculated are measured along actual highway and road links. Consignee/shipper locations that are less then 30 miles apart are aggregated in the same area. Assuming that the travel speed is 40 mph, the maximum travel time between locations within an area is 0.75 hours.

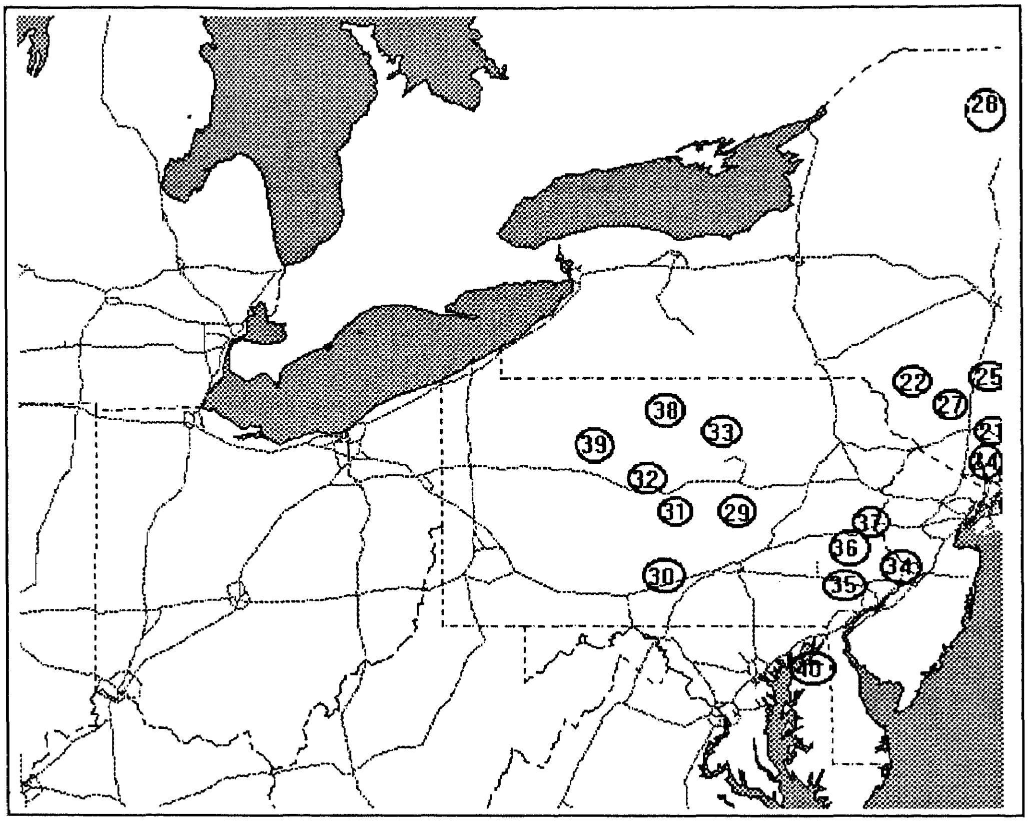


Figure 4.3 Consignee and Shipper Areas in the Northeast US, excluding those in New Jersey

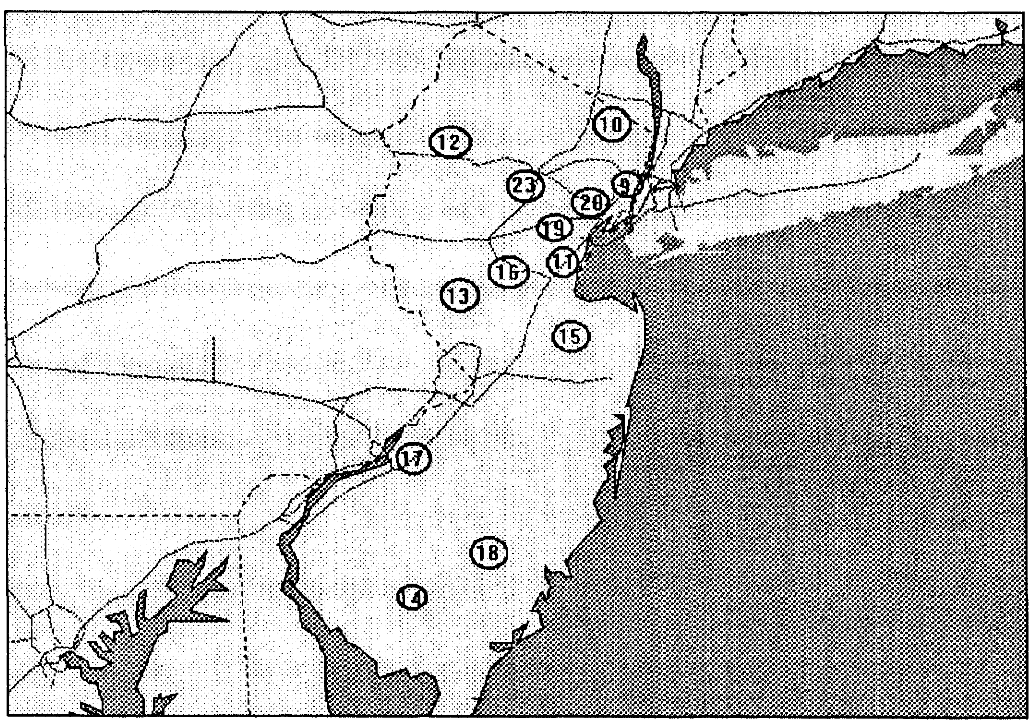


Figure 4.4 Consignee and Shipper Areas in New Jersey

4.4.2 Rates

The current rate is based on a round trip rate of moving a loaded container in one direction and returning it empty. The model requires rates for each movement. Thus, it was necessary to allocate a portion of these round trip rates to the loaded movement, empty movement, tractor idling, and bobtailing. This was accomplished by using the stay-with rates to determine a linear relationship between rates as a function of mileage. The regression formula is shown in Appendix C. The stay-with rate requires two hours of loading or unloading time. At $25 per hour, a charge of $50 for two hours of tractor idling is included in the rate. This charge was subtracted from the intercept yielding the regression formula: $y = 130.42 + 1.1236 * (2x)$,

where:

y = drayage rate, and

x = one-way distance in miles.

In the regression formula, the intercept represents fixed charge associated with terminal, administrative costs, etc. This charge must be allocated to both loaded and empty movements. Assuming two-thirds of the fixed costs are allocated to loaded movements, and one-third to the empty movements, the rate for one-directional movement is:

loaded movement: $y_l = 86.94 + 1.1236x$,

empty movement: $y_e = 43.47 + 1.1236x$,

where:

y_l = one-way rate for loaded containers,

y_e = one-way rate for empty containers, and

x = one-way distance traveled in miles.

The one directional rates from/to shipper/consignee areas derived using the above linear regression equations are listed in Appendix C. Tractor leasing rates are assumed to be $300 per day.

4.4.3 Demands

The spatial and temporal characteristics of the loads to be delivered are shown in Appendices D, while the loads to be picked up are shown in Appendix E. These loads are moved by a major drayage trucker. Some of the loads are moved by other drayage providers, and are shown in Appendices F and G. A total of 144 of those loads that were delivered to consignees were missing exact locations. This missing information was filled in by assigning these loads uniformly over the consignee areas served by the major drayage trucker. The missing information on shippers' loads and locations was estimated in a similar manner.

4.5 Some Practical Considerations

In the case study, the tractor-container drayage model was applied to a three week period and 40 consignee/shipper areas. The model is implemented in the General Algebraic Modeling System (GAMS) (Brooke et al., 1988). GAMS is a general purpose mathematical programming software. All the relevant data must be included in the model in a proper format. Since the problem size is very large, and initial data preparation work is intensive, preprocessing of data is preferable. Also, every effort should be made to reduce the model size because the solution time increase exponentially with model size. This following sections discuss these two aspects, namely, preprocessing of data and reduction of model size.

4.5.1 Data Preparation

The GAMS code requires the data input in either of two formats, as a complete data list or as a table which presents the data in matrix form. Since all the data in the case study have two dimensions, it is natural to use the table format. Any high level programming language such as C, PASCAL, FORTRAN and BASIC. In this case study, several preprocessing programs written in BASIC code are used to generate demand, activity time and cost tables.

The model also requires to develop several parameters to exclude infeasible departure times and areas which are not accessible at a particular time. All these parameters can be developed recursively by using the activity time data (Hallowell, 1989). This could be done in two ways: (1) use preprocessing programs to generate these parameters and input the data into the GAMS code, and (2) let GAMS itself generate these parameters. Since GAMS is a FORTRAN based software package, most algebraic operations on parameters can be easily accomplished. In this case study, the later is preferred because it is convenient and does not require extra data input from other software. However, this method has a disadvantage, because GAMS needs to generate these parameters first before doing the optimization. Initial runs of the model resulted in the following statistics showing the time consumed in each stage of the model run.

Model Generation: 2407 .7 seconds,

Execution : 3027.6 seconds, and

Resource Usage : 40237.6 seconds.

There are 3027.6 seconds spent on generating these parameters which account for 3027/(3027+2407+40237)= 6.6% of total run time. It is expected that the execution time can be reduced if the parameters are developed using preprocessing programs.

4.5.2 Model Size Reduction

Table 4.1 shows a GAMS partial solution listing with model statistics.

Table 4.1 Model Statistics

Block equations	7	Single equations	10843	Non zeros	545967
Block variables	6	Single variables	142153	Work space allocated: 25.40 Mb	

Obviously, as indicated by this table, the model requires enormous computational time. An approach for reducing the size of the model, shown in Appendix H, has been implemented. The model statistics for the original size and after the approach for reducing its size has been implemented are shown in Table 4.2. The Gams program code is shown in Appendix I.

Table 4.2 Model Size Comparison between the Original and Modified Models

	single equations	single variables	work space needed
original model	10843	142153	25.40 Mb
modified model	9771	90458	15.32 Mb

CHAPTER 5

CASE STUDY ANALYSIS RESULTS

5.1 Costs of Alternative Drayage System Designs

The costs of the current operation and of the alternatives are given in Table 5.1. The cost of the baseline is $104,692. The costs for the centralized drayage alternative with payment plans A, B, and C are $79,861, $82,222, and $84,545 respectively. The cost for plan D is calculated by multiplying the total tractor hours with the an hourly rate of $40/hour. The alternative with direct leasing of tractors represents a drayage system where the tractors and drivers are leased for a 15 day period. The cost of this alternative is $49,500, and it is calculated by multiplying the optimal number of tractors (11) with the lease rate of $300 per tractor-driver per day. The results indicate that savings of 23.7% can be achieved with the centralized drayage operation planning under Plan A over the baseline. Savings of 19.2% can be achieved with centralized planning and Plan C over the baseline. The operating cost for Plan D is approximately 38%, less than that of Plan C.

The cost of drayage could be further reduced by leasing a fleet of tractors. Leasing would reduce operating costs by 52.7% in comparison with the baseline cost.

5.2 Cost of a Single Centralized Operations vs. Independent Operations

To assess the economies of scale from having several truckers carrying out either centralized or independent and separate operations, three scenarios were analyzed. Scenario 1 assumes that there are many truckers in the same service area, a trucker X-

Table 5.1. Cost of Operation for the Alternative Drayage System Designs

Alternative	Cost of Operation	Reduction in Cost Relative to Baseline
Baseline	$104,692	---------------------
Centralized Drayage Operations Planning with Piece-Work Pricing		
Plan A.	$79,861	23.7%
Plan B.	$82,222	21.4%
Plan C	$84,545	19.2%
Plan D	$52,760	49.6%
Centralized Drayage Operation Planning with Direct Tractor Leasing	$49,500	52.7%

Truck that is operating according to a centralized plan, and several smaller truckers each operating independently. Scenario 2 assumes that there are two large truckers in the same service area, a trucker X-Truck and a trucker Y-Truck, each operating independently, but each having a centralized operation. Scenario 3 assumes that there is only one trucker, Z-

Truck, which operates according to a centralized plan, and capable of serving all loads. In each case, the operating cost is calculated using the drayage model.

The results are shown in Table 5.2 and indicate that there is no significant cost savings of a single centralized operation (Scenario 3) over the case with two independent centralized operations (Scenario 2). The saving is only $891 or 0.67%. There are two reasons for this small savings. First, there is a flow imbalance between deliveries and pick-ups. The ratio of loads to be delivered to those to be picked up is 243/40≅ 6.08. Therefore, there savings from picking up a shipper's load with a container that delivered a load in the vicinity are limited. Solution results show that 98% of all shipper's demand was matched with deliveries.

However, the situation is quite different when comparing the costs of Scenarios 1 and 3. By giving the loads currently moved by independent smaller truckers to the large Z-Truck, the cost of operation was decreased by 9.75%. This cost savings has resulted from the economies of traffic density because Z-Truck was able to match some of the pick ups at the shippers with the deliveries to the consignees and thus reduce the cost per load.

Table 5.2 Costs of Market Dominance Scenarios

Scenario	Cost (Plan C)	Reduction in Cost [%]
1. X-Truck and many truckers	$147,035	--
2. X-Truck and Y-Truck	$133,593	9.41
3. Z-Truck	$132,702	9.75

X-Truck and Y-Truck are assumed to have the same load delivery and pick up areas. This means that most of the shipper's demand was matched in the Y-Truck operation and there is a little chance for further reducing operating cost if these two operators were combined. Cost savings of a single centralized operation over two independent centralized operations could be larger if demands are distributed randomly in the whole service area. Since there is no real distribution data available, the cost savings can not be ascertained in this study.

5.3 Impacts of Service Time Variations

The impact of varying service time constraints on the consumption of resources (tractor hours) was investigated also. Specifically, the time windows (the maximum allowable time between load is availability for pick up or delivery and the time it is actually picked up or delivered) were investigated and the model was used to calculate the required resources (tractor hours). The results show that decreasing the allowed service time from three days to one day only increases the required tractor hours marginally from 1319 to 1349. This is understandable because due to load imbalance there is a tremendous opportunity to match most of the pick ups at shippers with deliveries to consignees in the vicinity.

CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH

The research, whose results were presented in this thesis accomplished there objectives. First, a model was used to evaluate ways for reducing costs and improving service quality of a drayage operation. The case study of the drayage operation at a South Kearny, New Jersey terminal indicated that the total operating cost could be reduced by 19.2 to 52.7% if the drayage operations were planned centrally, instead of on an independent basis. Second, the original model was modified by adding demand data as control parameters to reduce model size. It was shown that when the demand matrix has few non-zero elements, this method can reduce the problem size substantially. Third, several preprocessing algorithms were developed to facilitate data input.

Two avenues for future research are identified. First, the model tracks the movement of tractors and containers through space and each interval of the analysis period simultaneously. Clearly, as the length of the planning period, or the number of areas increases, the model size will increase exponentially, resulting in a long solution time. New methods for modeling the drayage operation need to be developed. A new solution method needs to be explored that will make a trade-off between solution accuracy and solution time.

The near network structure of the problem needs to be exploited to develop more efficient algorithms. Currently, the model is implemented in GAMS code and solved by the

MINOS5 solver. The MINOS5 solver treats this problem as a general LP problem and solves it by using the simplex method. Further research should be devoted to this area to identify more efficient solvers for the problem. A dedicated algorithm which explores this near network structure could solve the problem more efficiently. Second, the data input to the model requires a lot of spatial data such as each shipper/consignee location, and load characteristics. Therefore, integrating this model into a Geographic Information System (GIS) would make the model more practical, more user friendly and simplify data input. The required data input can be obtained directly from the GIS database and the model solution can be stored in the database and the resulting tractor and container activity presented in a graphic form.

APPENDIX A

Loads to be Delivered to and Picked Up from Consignee/Shipper Areas

Area	City	Zip Code	Delivery	Pick Up
1	Springfield	1111	1	0
	Oxford	1540	1	5
2	West Wareham	2576	0	1
	Fall River	2722	0	2
	Taunton	2780	2	0
3	Cranston	2920	1	0
4	Brattleboro	5301	14	0
5	Winsted	6098	2	0
	Cheshire	6410	2	0
	Durham	6422	1	1
6	Hartford	6101	1	1
	Cromwell	6416	2	0
	Dayville	6241	3	0
7	Waterbury	6719	2	0
	Meriden	6450	2	0
	Danbury	6810	0	1
8	Kearny	7032	2	0
	Carlstadt	7072	3	0
	Moonachie	7074	0	4
	Secaucus	7094	0	0
	Newark	7105	14	0
	Hillside	7205	1	0

Appendix A Loads to be Delivered to and Picked Up from Consignee/Shipper Areas (Continued)

8	Jersey City	7305	6	0
	Rutherford	7076	2	0
9	Garfield	7026	7	0
	Paterson	7501	2	2
	Hawthorne	7506	4	0
	South Hackensack	7606	8	0
	Englewood	7631	1	0
10	Englishtown	7726	1	0
11	Succasunna	7876	2	0
12	Burlington	8016	28	1
13	Vineland	8360	0	1
	Millville	8332	1	9
14	Trenton	8638	1	0
15	Dayton	8810	4	0
16	Bridgeport	8104	60	0
17	Elwood Park	7407	1	1
18	E. Brunswick	8816	1	0
	N. Brunswick	8902	2	0
19	Middlesex	8846	1	0
	South River	8882	1	0
20	Brewster	10509	1	0
	Ossining	10562	1	0
21	Middletown	10940	7	0
22	Ogensburg	7439	3	0

Appendix A Loads to be Delivered to and Picked Up from Consignee/shipper Areas (Continued)

23	Long Island City	11101	1	0
	Brooklyn	11232	1	2
24	Jamaica	11433	2	0
	Alberston	11507	1	1
	Freeport	11520	0	4
	Plainview	11803	4	0
25	Ronkonkama	11779	1	0
26	Maspeth	11354	1	0
27	Guidland Center	12085	9	0
28	Camp Hill	17011	0	1
29	Machanisburg	17055	4	0
30	Lititz	17543	2	0
31	Pottsville	17901	0	1
32	Laftin	18072	3	0
33	Bristol	19007	3	0
34	Chester	19013	0	1
35	Bensalem	19020	0	1
36	Phliladelphia	19154	5	0
	King of Prussia	19406	2	0
37	Leona	17540	1	0
38	University Park	16802	0	0
39	Jessup	20794	1	0
	Glen Burnie	21061	0	0
40	Calverton	11933	3	0
	Total		243	40

APPENDIX B

Aggregation of Consignee/Shipper Zip Codes and Cities into Areas

Area	Zip Codes	Cities
1	01111, 01540	Springfield, Oxford
2	02576, 02722, 02780	West Wareham, Fall River, Taunton
3	02920	Cranston
4	05301	Battleboro
5	06098, 06410, 06422	Winsted, Cheshire, Durham
6	06101, 06416, 06421	Hartford, Cromwell, Dayville
7	06719, 06450, 06810	Waterbury, Meriden, Danbury
8	07032, 07022, 07074, 07094, 07105, 07205, 07305, 07070	Kearny, Carlstadt, Moonachie, Secaucus, Newark, Hillside, Jersey City, Rutherford
9	07026, 07501, 07506, 07606, 07631	Garfield, Paterson, Hawthorne, South Hackensack, Englewood
10	07726	Englishtown
11	07876	Succasunna
12	08016	Burlington
13	08360, 08332	Vineland, Millville
14	08638	Trenton
15	08810	Dayton
16	08104	Bridgeport
17	07407	Elwood Park
18	08816, 08902	East Brunswick, North Brunswick
19	08846, 08882	Middlesex, South River

Appendix B Aggregation of Consignee/Shipper Zip Codes and Cities into Areas (Continued)

20	10509, 10562	Brewster, Ossining
21	10940	Middletown
22	07439	Ogensburg
23	11101, 11232	Long Island City, Brooklyn
24	11433, 11507,11520, 11803	Jamaica, Alberston, Freeport, Plainview
25	11779	Ronkonkoma
26	11354	Maspeth
27	12085	Guilderland Center
28	17011	Camp Hill
29	17055	Mechanicsburg
30	17543	Lititz
31	17901	Pottsville
32	18702	Laflin
33	19007	Bristol
34	19013	Chester
35	19020	Bensalem
36	19154, 19406	Philadelphia, King of Prussia
37	17540	Leona
38	16802	University Park
39	20794, 21061	Jessup, Glen Burnie
40	11933	Carlverton

APPENDIX C

Linear Regression for Rates as Function of Distance

Destination	One Way Distance	Rate
Kearny, NJ	1	152
Newark, NJ	4	166
Jersey City, NJ	5	152
Rutherford, NJ	7	152
Carlstadt, NJ	8	152
Hillside, NJ	8	152
Moonachie, NJ	11	166
South Hackensack, NJ	11	166
Brooklyn, NY	12	366
Garfield, NJ	14	166
Hawthorne, NJ	15	166
Maspeth, NY	15	366
Englewood, NJ	16	166
Paterson, NJ	16	166
Elmwood Park, NJ	17	166
Long Island City, NY	17	366
Jamaica, NY	21	366
East Brunswick, NJ	28	185
Middlesex, NJ	28	185
South River, NJ	30	185
Succasunna, NJ	31	539
Albertson, NY	33	380

Appendix C Linear Regression for Rates as Function of Distance (Continued)

North Brunswick, NJ	33	200
Dayton, NJ	38	200
Freeport, NY	40	200
Englishtown, NJ	43	209
Ogdensburg, NJ	44	209
Plainview, NY	44	394
Ogdensburg, NJ	49	209
Ossining, NY	49	394
Trenton, NJ	55	343
Middletown, NY	65	390
Ronkonkoma, NY	67	456
Burlington, NJ	68	343
Millville, NJ	68	471
Bensalem, PA	69	364
Bristol, PA	69	364
Brewster, NY	69	417
Danbury, CT	78	408
Philadelphia, PA	84	385
Calverton, NY	86	523
Philadelphia, PA	89	385
King of Prussia, PA	97	420
Cheshire, CT	103	416
Bridgeport, NJ	105	404
Waterbury, CT	106	428

Appendix C Linear Regression for Rates as Function of Distance (Continued)

Chester, PA	107	386
Meriden, CT	110	444
Durham, CT	114	461
Cromwell, CT	115	465
Vineland, NJ	117	450
Millville, NJ	124	471
Hartford, CT	125	343
Pottsville, PA	125	451
Laflin, PA	126	437
Winsted, CT	132	471
Leola, PA	140	486
Lititz, PA	142	513
Springfield, MA	151	510
Guilderland Center, NY	155	539
Camp Hill, PA	165	558
Mechanicsburg, PA	168	568
Dayville, CT	174	546
Oxford, MA	180	565
Cranston, RI	186	584
Jessup, MD	202	596
Taunton, MA	204	635
Fall River, MA	206	626
Taunton, MA	206	635
Brattleboro, VT	212	643
West Wareham, MA	236	684

Linear regression equation:

$y = 180.424 + 2.247 * x$

where:

y is two way rate, and

x is one way distance.

Coefficient of Correlation (R) = 0.936835

Confidence interval for parameters (with 70 degrees of freedom, 0.05 confidence level)

$165.66 \leq \alpha \leq 186.38$

$2.1721 \leq \beta \leq 2.3714$

APPENDIX D

Loads to be Delivered, Sorted by Area and Date, X-Truck

April 25, to May 2, 1994

		Before 04/25	04/25	04/26	04/27	04/28	04/29	05/02
z2	Springfield	1						
	Oxford			1				
z3	West Wareham							
	Fall River							
	Taunton	2						
z4	Cranston							
z5	Brattleboro				4	8		
z6	Winsted							
	Cheshire							2
	Durham							1
z7	Hartford				1			
	Cromwell	1						
	Dayville							
z8	Waterbury							
	Meriden							
	Danbury							
z9	Kearny							2
	Carlstadt	1						
	Moonachie							
	Secaucus							
	Newark				3			8
	Hillside							
	Jersey City				4			
	Rutherford				1			1
z10	Garfield					2		
	Paterson		2					
	Hawthorne							
	Hackensack			1		4		
	Englewood	1						
z11	Englishtown	1						
z12	Succasunna							2
z13	Burlington	4		3		1	4	2
z14	Vineland							
	Millville							1
z15	Trenton							
z16	Dayton	1			1		2	
z17	Bridgeport	4	2			3	2	13

Appendix D Loads to be Delivered, Sorted by area and date, X-Truck (Continued)

April 25, to May 2, 1994

z18	Elwood Park	1						
z19	E Brunswick							
	N Brunswick						2	
z20	Middlesex		1					
	South River	1						
z21	Brewster	1						
	Ossining	1						
z22	Middletown			1	2	2		1
z23	Ogensburg			1		2		
z24	Long Island City							
	Brooklyn							1
z25	Jamaica							
	Alberston	1						
	Freeport							
	Plainview	2						
z26	Ronkonkama	1						
z27	Maspeth	1						
z28	Guidland Center		2			2		
z29	Camp Hill							
z30	Machanisburg							
z31	Lititz			1				
z32	Pottsville							
z33	Laftin	3						
z34	Bristol							
z35	Chester							
z36	Bensalem							
z37	Philadelphia	1						2
	King Of Prussia							
z38	Leona							
z39	University Park							
z40	Jessup							
	Glen Burnie							
z41	Calverton							
	Subtotal	29	7	8	16	24	10	36

Appendix D Loads to be Delivered, Sorted by Area and Date, X-Truck (Continued)

May 3, to May 13, 1994

		05/03	05/04	05/05	05/06	05/09	05/10	05/11	05/12	05/13
z2	Springfield									
	Oxford									
z3	West Wareham									
	Fall River									
	Taunton									
z4	Cranston					1				
z5	Brattleboro					2				
z6	Winsted							2		
	Cheshire									
	Durham									
z7	Hartford									
	Cromwell				1					
	Dayville		1	2						
z8	Waterbury			2						
	Meriden	2								
	Danbury									
z9	Kearny									
	Carlstadt				1			1		
	Moonachie									
	Secaucus									
	Newark		3							
	Hillside		1							
	Jersey City					2				
	Rutherford									
z10	Garfield			2		2			1	
	Paterson									
	Hawthorne					2	2			
	Hackensack		1				2			
	Englewood									
z11	Englishtown									
z12	Succasunna									
z13	Burlington	2		10	2					
z14	Vineland									
	Millville									
z15	Trenton		1							
z16	Dayton									
z17	Bridgeport	3			6		4	17		6
z18	Elwood Park									

Appendix D Loads to be Delivered, Sorted by Area and Date, X-Truck (Continued)

May 3, to May 13, 1994

z19	E Brunswick				1					
	N Brunswick									
z20	Middlesex									
	South River									
z21	Brewster									
	Ossining									
z22	Middletown					1				
z23	Ogensburg									
z24	Long Island City			1						
	Brooklyn									
z25	Jamaica							2		
	Alberston									
	Freeport									
	Plainview			2						
z26	Ronkonkama									
z27	Maspeth									
z28	Guidland Center		2			2		1		
z29	Camp Hill									
z30	Machanisburg				2	2				
z31	Lititz		1							
z32	Pottsville									
z33	Laftin									
z34	Bristol			1				2		
z35	Chester									
z36	Bensalem									
z37	Phliladelphia					2				
	King Of Prussia			2						
z38	Leona				1					
z39	University Park									
z40	Jessup				1					
	Glen Burnie									
z41	Calverton					1		2		
	Subtotal	7	10	22	15	17	8	27	1	6

APPENDIX E

Loads to be Picked Up, Sorted by Area and Date, X-Truck

April 25, to May 2, 1994

		Before 04/25	04/25	04/26	04/27	04/28	04/29	05/02
z2	Springfield	1						
	Oxford			1				
z3	West Wareham							
	Fall River							
	Taunton	2						
z4	Cranston							
z5	Brattleboro				4	8		
z6	Winsted							
	Cheshire							2
	Durham							1
z7	Hartford				1			
	Cromwell	1						
	Dayville							
z8	Waterbury							
	Meriden							
	Danbury							
z9	Kearny							2
	Carlstadt	1						
	Moonachie							
	Secaucus							
	Newark				3			8
	Hillside							
	Jersey City				4			
	Rutherford				1			1
z10	Garfield					2		
	Paterson		2					
	Hawthorne							
	Hackensack			1		4		
	Englewood	1						
z11	Englishtown	1						
z12	Succasunna							2
z13	Burlington	4		3		1	4	2
z14	Vineland							
	Millville							1
z15	Trenton							
z16	Dayton	1			1		2	

Appendix E Loads to be Picked Up, Sorted by Area and date, X-Truck(Continued)

April 25, to May 2, 1994

z17	Bridgeport	4	2			3	2	13
z18	Elwood Park	1						
z19	E Brunswick							
	N Brunswick						2	
z20	Middlesex		1					
	South River	1						
z21	Brewster	1						
	Ossining	1						
z22	Middletown			1	2	2		1
z23	Ogensburg			1		2		
z24	Long Island City							
	Brooklyn							1
z25	Jamaica							
	Alberston	1						
	Freeport							
	Plainview	2						
z26	Ronkonkama	1						
z27	Maspeth	1						
z28	Guidland Center		2			2		
z29	Camp Hill							
z30	Machanisburg							
z31	Lititz			1				
z32	Pottsville							
z33	Laftin	3						
z34	Bristol							
z35	Chester							
z36	Bensalem							
z37	Philadelphia	1						2
	King Of Prussia							
z38	Leona							
z39	University Park							
z40	Jessup							
	Glen Burnie							
z41	Calverton							
	Subtotal	29	7	8	16	24	10	36

Appendix E Loads to be Picked Up, Sorted by Area and Date, X-Truck (Continued)

May 3, to May 13, 1994

		05/03	05/04	05/05	05/06	05/09	05/10	05/11	05/12	05/13
z2	Springfield									
	Oxford									
z3	West Wareham									
	Fall River									
	Taunton									
z4	Cranston					1				
z5	Brattleboro					2				
z6	Winsted							2		
	Cheshire									
	Durham									
z7	Hartford									
	Cromwell				1					
	Dayville		1	2						
z8	Waterbury			2						
	Meriden	2								
	Danbury									
z9	Kearny									
	Carlstadt				1			1		
	Moonachie									
	Secaucus									
	Newark		3							
	Hillside		1							
	Jersey City					2				
	Rutherford									
z10	Garfield			2		2			1	
	Paterson									
	Hawthorne					2	2			
	Hackensack		1				2			
	Englewood									
z11	Englishtown									
z12	Succasunna									
z13	Burlington	2		10	2					
z14	Vineland									
	Millville									
z15	Trenton		1							
z16	Dayton									
z17	Bridgeport	3			6		4	17		6
z18	Elwood Park									

Appendix E Loads to be Picked Up, Sorted by Area and Date, X-Truck(Continued)

May 3, to May 13, 1994

z19	E Brunswick				1					
	N Brunswick									
z20	Middlesex									
	South River									
z21	Brewster									
	Ossining									
z22	Middletown					1				
z23	Ogensburg									
z24	Long Island City			1						
	Brooklyn									
z25	Jamaica							2		
	Alberston									
	Freeport									
	Plainview			2						
z26	Ronkonkama									
z27	Maspeth									
z28	Guidland Center		2			2		1		
z29	Camp Hill									
z30	Machanisburg				2	2				
z31	Lititz		1							
z32	Pottsville									
z33	Laftin									
z34	Bristol			1				2		
z35	Chester									
z36	Bensalem									
z37	Pliladelphia					2				
	King Of Prussia			2						
z38	Leona				1					
z39	University Park									
z40	Jessup				1					
	Glen Burnie									
z41	Calverton					1		2		
	Subtotal	7	10	22	15	17	8	27	1	6

APPENDIX F

Loads to be Delivered, Sorted by Area and Date, non X-Truck

April 25, to May 2, 1994

		Before 04/25	04/25	04/26	04/27	04/28	04/29	05/02
z2	Springfield			1				
	Oxford		2					
z3	West Wareham		2					
	Fall River							
	Taunton	2						
z4	Cranston							
z5	Brattleboro					1		
z6	Winsted							
	Cheshire							
	Durham							1
z7	Hartford	2						
	Cromwell							
	Dayville							
z8	Waterbury							
	Meriden							
	Danbury							
z9	Kearny							
	Carlstadt							1
	Moonachie							
	Secaucus							2
	Newark	1						
	Hillside							1
	Jersey City		1					
	Rutherford							
z10	Garfield	2						
	Paterson			1				
	Hawthorne					1		
	Hackensack		2					
	Englewood							
z11	Englishtown	2						
z12	Succasunna							1
z13	Burlington	6		3		1	1	1
z14	Vineland							
	Millville							
z15	Trenton							

Appendix F Loads to be Delivered, Sorted by Area and date,non X-Truck (Continued)

April 25, to May 2, 1994

z16	Dayton	1						
z17	Bridgeport		9					4
z18	Elwood Park		1					
z19	E Brunswick							
	N Brunswick							
z20	Middlesex		3					
	South River							
z21	Brewster		1					
	Ossining		2					
z22	Middletown			1				
z23	Ogensburg							
z24	Long Island City							
	Brooklyn							
z25	Jamaica	2						
	Alberston		1					
	Freeport							
	Plainview		1					
z26	Ronkonkama		1					
z27	Maspeth		1					
z28	Guidland Center		3					
z29	Camp Hill							
z30	Machanisburg							
z31	Lititz			1				
z32	Pottsville							
z33	Laftin		4					
z34	Bristol							
z35	Chester							
z36	Bensalem							
z37	Philadelphia		2					1
	King Of Prussia							
z38	Leona							
z39	University Park							
z40	Jessup							
	Glen Burnie							
z41	Calverton							
	Subtotal	18	36	7	0	3	1	12

Appendix F Loads to be Delivered, Sorted by Area and Date, non X-Truck (Continued)

May, 3 to May,13, 1994

		05/4	05/5	05/6	05/9	05/10	05/11	05/12
z2	Springfield							
	Oxford							
z3	West Wareham							
	Fall River							
	Taunton							
z4	Cranston				1			
z5	Brattleboro				1			
z6	Winsted						1	
	Cheshire							
	Durham							
z7	Hartford							
	Cromwell	1		1				
	Dayville		1					
z8	Waterbury							
	Meriden		1					
	Danbury							
z9	Kearny	2						
	Carlstadt			1				
	Moonachie				1			
	Secaucus							
	Newark						1	
	Hillside							
	Jersey City	1						
	Rutherford							
z10	Garfield							
	Paterson	1			2			8
	Hawthorne		1			1		
	Hackensack							
	Englewood							
z11	Englishtown							
z12	Succasunna							
z13	Burlington		2	1				
z14	Vineland							
	Millville							
z15	Trenton							
z16	Dayton							
z17	Bridgeport			3		1	3	
z18	Elwood Park							

Appendix F Loads to be Delivered, Sorted by Area and Date, non X-Truck (Continued)

May, 3 to May,13, 1994

z19	E Brunswick							
	N Brunswick							
z20	Middlesex							
	South River							
z21	Brewster							
	Ossining							
z22	Middletown				1			
z23	Ogensburg							
z24	Long Island City							
	Brooklyn							
z25	Jamaica							
	Alberston							
	Freeport							
	Plainview							
z26	Ronkonkama							
z27	Maspeth							
z28	Guidland Center	2			1			
z29	Camp Hill							
z30	Machanisburg			1	1			
z31	Lititz	1						
z32	Pottsville							
z33	Laftin							
z34	Bristol							
z35	Chester							
z36	Bensalem							
z37	Philadelphia				1			
	King Of Prussia							
z38	Leona							
z39	University Park							
z40	Jessup							
	Glen Burnie							
z41	Calverton				1			

APPENDIX G

Loads to be Picked Up, Sorted by Area and Date, non X-Truck

April 25, to May 2, 1994

		Before 04/25	04/25	04/26	04/27	04/28	04/29	05/2
z2	Springfield	3						
	Oxford		1					
z3	West Wareham			1				
	Fall River							
	Taunton							
z4	Cranston							
z5	Brattleboro							
z6	Winsted							
	Cheshire							
	Durham							
z7	Hartford							
	Cromwell							
	Dayville							
z8	Waterbury							
	Meriden							
	Danbury							
z9	Kearny							
	Carlstadt							
	Moonachie							
	Secaucus							
	Newark							1
	Hillside							
	Jersey City							
	Rutherford							
z10	Garfield							
	Paterson							
	Hawthorne							
	Hackensack							
	Englewood							
z11	Englishtown							
z12	Succasunna							
z13	Burlington							
z14	Vineland		2					
	Millville					1		
z15	Trenton							

Appendix G Loads to be Picked Up, Sorted by Area and Date, non X-Truck (Continued)

April 25, to May 2, 1994

z16	Dayton							
z17	Bridgeport							
z18	Elwood Park							
z19	E Brunswick							
	N Brunswick							
z20	Middlesex							
	South River							
z21	Brewster							
	Ossining							
z22	Middletown							
z23	Ogensburg							
z24	Longisland City		2					
	Brooklyn							
z25	Jamaica							
	Alberston		1					
	Freeport							1
	Plainview							
z26	Ronkonkama							
z27	Maspeth							
z28	Guidland Center							
z29	Camp Hill							
z30	Machanisburg							
z31	Lititz							
z32	Pottsville							
z33	Laftin							
z34	Bristol							
z35	Chester							
z36	Bensalem							
z37	Philadelphia							
	King of Prussia							
z38	Leona							
z39	University Park							
z40	Jessup							
	Glen Burnie							
z41	Calverton							
	Subtotal	3	6	1	0	1	0	2

Appendix G Loads to be Picked Up, Sorted by Area and Date, non X-Truck (Continued)

May 3, to May 13, 1994

		05/3	05/4	05/5	05/6	05/9	05/10	05/11	05/12	05/13
z2	Springfield									
	Oxford				1					1
z3	West Wareham									
	Fall River	1								
	Taunton					1				
z4	Cranston									
z5	Brattleboro									
z6	Winsted									
	Cheshire									
	Durham								1	
z7	Hartford									
	Cromwell									
	Dayville									
z8	Waterbury									
	Meriden									
	Danbury							1		
z9	Kearny									
	Carlstadt									1
	Moonachie									
	Secaucus									
	Newark									
	Hillside									
	Jersey City									
	Rutherford									
z10	Garfield									
	Paterson									
	Hawthorne					1				
	Hackensack									
	Englewood									
z11	Englishtown									
z12	Succasunna									
z13	Burlington									
z14	Vineland									
	Millville		1	1						
z15	Trenton									
z16	Dayton									
z17	Bridgeport									
z18	Elwood Park									

Appendix G Loads to be Picked Up, Sorted by Area and Date, non X-Truck (Continued)

May 3, to May 13, 1994

z19	E Brunswick									
	N Brunswick									
z20	Middlesex									
	South River									
z21	Brewster									
	Ossining									
z22	Middletown									
z23	Ogensburg									
z24	Longisland City									
	Brooklyn									
z25	Jamaica									
	Alberston									
	Freeport									
	Plainview									
z26	Ronkonkama									
z27	Maspeth									
z28	Guidland Center									
z29	Camp Hill									
z30	Machanisburg									
z31	Lititz									
z32	Pottsville									
z33	Laftin									
z34	Bristol									
z35	Chester									
z36	Bensalem									
z37	Philadelphia									
	King Of Prussia									
z38	Leona									
z39	University Park									
z40	Jessup									
	Glen Burnie									
z41	Calverton									
	Subtotal	1	1	1	1	2	0	1	1	2

APPENDIX H

Reducing Model Size

In the case study, demand data, designated as CDEMANDS(X,T) and SDEMANDS(X,T) in GAMS code, are two dimensional arrays. Argument X represents the set of origination areas while argument T represents the set of time periods. This array has a sparse matrix characteristics (i.e., there are a lot of zero elements) which could be exploited to reduce the model size. Two approaches are proposed. The first approach reduces the number of areas by assigning the demands in an area to its nearest area(s). A matching algorithm with the following steps is used:

Step 0. Initialization: Let AA(Zi, Zj)= TT(Zi, Zj)

Step 1. Pick up an area Zi that has total demand 1 at time T.

Step 2. Look up the activity table and find an area which has the smallest activity time between i and this area j, T=AA(zi,zj), let AA(Zi,Zj)=1,000.

Step 3. Look up the demand table CDEMANDS(X,T) and SDEMANDS(X,T) at time interval (T, T+time window), if there is a demand in that period, then let T'= time period such that CDEMANDS(X,T') or SDEMANDS(X,T') is not zero, go to step 4. Otherwise, go to step 5.

Step 4. Assign this load on Zj and reduce time window at area J to T'-T days, add cost to final optimized result. Stop, matching succeeded.

Step 5 If all AA(Zi,Zj)=1000 then stop, matching failed; Otherwise go to step 2.

The problem of this approach is that it requires changing two dimensional parameters RDEPART(R,T), used to represent a time window (service quality constraint), to three dimensional parameters RDEPART(A,R,T) to account for different time window requirements at different areas. Another problem is that whenever a match is made, the spatial information (number of areas) has to be changed accordingly. This, in turn, requires a regeneration of almost all the tables (costs, demands, activity times).

The second approach is to use the sparse matrix directly to reduce the number of variables. From the model formulation, the following is observed:

- If there are no loads to be delivered to area A, then there will be no flows of loaded tractor-containers from the terminal to that area (CDEMANDS(A,R) = 0 then OUT(A,T,R) = 0 $\forall$ T),
- If there are no loads to be picked up at area A, then there will be no flows of loaded tractor-containers from the area to the terminal (SDEMANDS(A,R) = 0 then IN(A,T,R) = 0 $\forall$ T),
- If there are no loads to be picked up at area A, then there will be no flow of empty tractor-containers from the terminal and other consignees to area A (E(X,A,T) = 0 $\forall$ X, T),
- If there are no loads to be delivered to area A, then there will be no flow of empty tractor-containers from the area to the terminal and other shippers (E(A,X,T) = 0 $\forall$ X, T),
- If there are neither consignee nor shipper demand at time interval (t-20, t) in area A, then B(A,A,T) = 0 $\forall$ T.

Define:

$$cdem(A) = \sum_R cdemands(A,R)$$

$$sdem(A) = \sum_R sdemands(A,R)$$

$$tract(A,T) = \sum_{T-20 \le R \le T} (sdemands(A,R) + cdemands(A,R))$$

Then

out(A,T,R)$cdemands(A,R) = 0 if cdemands(A,R) = 0,
in (A,T,R)$sdemands(A,R) = 0 if sdemands(A,R) = 0,

E(X,A,T)$(sdem(A) and cdem(X)) = 0 if either sdem(A)=0 or cdem(X)=0,

B(A,A,T)$tract(A,T) = 0 if tract(a,t) = 0

Since the demand matrix is a sparse matrix, it is expected that adding above control parameters to the variables will reduce the model size greatly. In the modified model, all control parameters are added symmetrically on both sides of the constraints, so the hidden network structure of the original problem is retained.

APPENDIX I

GAMS Program

```
$TITLE BON VOYAGE MONSIGNEUR SPASOVICH 2/14/90  SFH/LNS

* Program Description

* This program solves the linear programming formulation of the model of

* tractor and trailers delivery, pick up and repositioning system.

* see page 164 of GAMS manual for explanation of OPTION statements.

$OFFSYMXREF

$OFFSYMLIST

OPTION LIMROW =0 ;

OPTION LIMCOL = 0 ;

OPTION OPTCR = 0.001 ;

OPTION OPTCA = 0 ;

OPTION RESLIM = 8880000 ;

OPTION ITERLIM  = 8880000 ;

*OPTION LP = BDMLP

OPTION LP = MINOS5 ;

*OPTION LP = ZOOM ;

OPTION SOLPRINT = OFF ;

SETS
```

```
  X    areas and terminal /z1*z41/

  T    time periods /0*150/

  I    intermodal terminal /z1/

TEXT  descriptions used in report output parameter /'OUT','IN',
      'END','EMPTY','TRAILERS','STAY','network','(feasible)',
      'BOBTAIL','TOTALCOST','for','lp2c', 'Tractor','Trailer','Hours',
      '1day','2day','3day','4day','5day','6day','7day','8day', '9day','10day','11day','12day',
      '13day','14day','15day', '1a','2a','2c', '2a.1','2a.2','2a.3','2a.4', '2a.5','2a.6', '2a.7',
      '2a.8', '2a.9','2a.10','2a.11','2a.12','2a.13','2a.14','2a.15', '2b.1','2b.2','2b.3',
      '2b.4','2b.5','2b.6','2b.7','2b.8', '2b.9','2b.10','2b.11','2b.12', '2b.13','2b.14',
      '2b.15', '2c.1','2c.2','2c.3','2c.4','2c.5','2c.6','2c.7','2c.8', '2c.9','2c.10','2c.11','2c.12',
      '2c.13','2c.14','2c.15', 'DELIVERY','PICKUP','MARGINAL' /
ALIAS (T,T1,T2,R,R1,R2,R3,T3,S);
ALIAS (X,X1,A,J);
SCALARS
  NUMDAYS     number of days  /15/
  NUMPERIODS  number of periods per day /10/
  TRACTTIME   number of one hour periods to load or unload trailer /2/
  TIMEWINDOW  maximum allowable delay in pick up or delivery /3/;
parameter tract(a,t);
parameter sdem(a);
parameter cdem(a);
PARAMETER WINDEX(R);
WINDEX(R)= 10*FLOOR((ORD(R)-1)/10);
PARAMETER FPERIOD(T) / 0 = 1 / ;
PARAMETER DAY1(T) / (0*9) = 1 / ;
```

```
PARAMETER DAY2(T) / (10*19) = 1 / ;
PARAMETER DAY3(T) / (20*29) = 1 / ;
PARAMETER DAY4(T) / (30*39) = 1 / ;
PARAMETER DAY5(T) / (40*49) = 1 / ;
PARAMETER DAY6(T) / (50*59) = 1 / ;
PARAMETER DAY7(T) / (60*69) = 1 / ;
PARAMETER DAY8(T) / (70*79) = 1 / ;
PARAMETER DAY9(T) / (80*89) = 1 / ;
PARAMETER DAY10(T) / (90*99) = 1 / ;
PARAMETER DAY11(T) / (100*109) = 1 / ;
PARAMETER DAY12(T) / (110*119) = 1 / ;
PARAMETER DAY13(T) / (120*129) = 1 / ;
PARAMETER DAY14(T) / (130*139) = 1 / ;
PARAMETER DAY15(T) / (140*149) = 1 / ;
PARAMETER ENDPER(T) / (9,19,29,39,49,59,69,79,89,99,109,119,129,
139,149) = 1 /;
PARAMETER SAMEDAY(T,T2) /
  (0*9).(0*9)     = 1
  (10*19).(10*19) = 1
  (20*29).(20*29) = 1
  (30*39).(30*39) = 1
  (40*49).(40*49) = 1
  (50*59).(50*59) = 1
  (60*69).(60*69) = 1
  (70*79).(70*79) = 1
  (80*89).(80*89) = 1
  (90*99).(90*99) = 1
```

(100*109).(100*109) = 1

(110*119).(110*119) = 1

(120*129).(120*129) = 1

(130*139).(130*139) = 1

(140*149).(140*149) = 1 /;

TABLE TT(X,X1) activity time (in 1 hour periods) for tractors with loaded

* trailers going from area X to area X1 (includes running time,

* hitching/unhitching time, and time to process paperwork).

* tractor are travelling with average speed of 40mph

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
Z1	0	5	6	5	6	3	4	3	1	1	1	1	2	3	2
Z2	5	0	3	3	2	2	1	1	4	4	5	5	6	7	5
Z3	6	3	0	1	4	3	3	3	6	5	7	6	7	8	7
Z4	5	3	1	0	3	3	2	2	5	5	6	6	7	8	6
Z5	6	2	4	3	0	3	2	3	6	5	7	6	7	8	7
Z6	3	2	3	3	3	0	1	1	3	3	4	4	5	6	4
Z7	4	1	3	2	2	1	0	1	3	3	5	4	5	6	5
Z8	3	1	3	2	3	1	1	0	3	3	4	4	5	6	4
Z9	1	4	6	5	6	3	3	3	0	1	1	1	2	3	2
Z10	1	4	5	5	5	3	3	3	1	0	2	1	2	3	2
Z11	1	5	7	6	7	4	5	4	1	2	0	2	1	2	1
Z12	1	5	6	6	6	4	4	4	1	1	2	0	2	3	2
Z13	2	6	7	7	7	5	5	5	2	2	1	2	0	1	1
Z14	3	7	8	8	8	6	6	6	3	3	2	3	1	0	2
Z15	2	5	7	6	7	4	5	4	2	2	1	2	1	2	0
Z16	1	5	6	6	6	4	4	4	1	2	1	2	1	2	1
Z17	3	7	8	8	8	6	6	6	3	3	2	3	1	1	2
Z18	1	7	8	8	8	6	6	6	3	3	2	3	2	1	2
Z19	1	5	6	6	6	4	4	4	1	1	1	2	1	2	1
Z20	1	5	6	4	6	4	4	4	1	1	1	1	2	3	1
Z21	2	3	4	5	4	1	2	2	2	2	3	3	4	5	3
Z22	2	4	6	6	5	3	3	3	2	2	3	2	4	5	3
Z23	1	5	6	5	6	3	4	8	1	1	2	1	3	4	2
Z24	1	4	5	5	5	3	3	3	1	1	2	2	2	3	2
Z25	1	3	5	4	5	2	3	2	1	1	2	2	3	4	2
Z26	2	3	4	4	5	2	2	2	2	2	3	3	4	5	3
Z27	1	8	8	8	4	8	8	8	8	8	8	8	8	4	8
Z28	4	3	6	5	8	4	3	4	5	4	6	5	6	7	6
Z29	4	8	8	8	2	7	7	7	4	5	5	4	4	3	4

Z30	5	8	8	8	8	7	8	7	5	5	5	4	4	4	4
Z31	4	8	8	8	8	7	7	7	4	4	4	4	3	3	3
Z32	3	7	8	8	8	6	6	6	3	4	4	3	3	3	3
Z33	3	6	8	7	8	5	6	5	3	4	4	3	4	4	4
Z34	2	6	7	7	7	5	5	5	2	2	1	2	1	2	1
Z35	3	7	8	7	8	5	6	5	3	3	2	3	1	1	1
Z36	2	8	8	8	8	8	8	8	8	8	8	7	7	7	7
Z37	3	6	8	7	8	5	6	5	2	3	2	3	1	1	1
Z38	4	8	8	8	8	6	7	6	4	4	4	3	3	3	3
Z39	6	8	8	8	8	8	8	8	6	6	7	5	6	6	6
Z40	5	8	8	8	8	8	8	8	5	6	5	5	4	3	4
Z41	2	3	4	4	4	2	2	2	2	2	3	3	4	5	4

	+Z16	Z17	Z18	Z19	Z20	Z21	Z22	Z23	Z24	Z25	Z26	Z27	Z28	Z29	Z30
Z1	1	3	1	1	1	2	2	1	1	1	2	1	4	4	5
Z2	5	7	7	5	5	3	4	5	4	3	3	8	3	8	8
Z3	6	8	8	6	6	4	6	6	5	5	4	8	6	8	8
Z4	6	8	8	6	4	5	6	5	5	4	4	8	5	8	8
Z5	6	8	8	6	6	4	5	6	5	5	5	4	8	2	8
Z6	4	6	6	4	4	1	3	3	3	2	2	8	4	7	7
Z7	4	6	6	4	4	2	3	4	3	3	2	8	3	7	8
Z8	4	6	6	4	4	2	3	8	3	2	2	8	4	7	7
Z9	1	3	3	1	1	2	2	1	1	1	2	8	5	4	5
Z10	2	3	3	1	1	2	2	1	1	1	2	8	4	5	5
Z11	1	2	2	1	1	3	3	2	2	2	3	8	6	5	5
Z12	2	3	3	2	1	3	2	1	2	2	3	8	5	4	4
Z13	1	1	2	1	2	4	4	3	2	3	4	8	6	4	4
Z14	2	1	1	2	3	5	5	4	3	4	5	4	7	3	4
Z15	1	2	2	1	1	3	3	2	2	2	3	8	6	4	4
Z16	0	2	2	1	1	3	3	2	2	2	3	8	5	4	5
Z17	2	0	2	2	2	5	4	4	3	4	5	8	7	3	3
Z18	2	2	0	2	3	5	5	4	3	4	5	8	7	4	5
Z19	1	2	2	0	1	3	3	2	1	2	3	8	5	4	5
Z20	1	2	3	1	0	3	3	2	1	2	3	8	5	4	4
Z21	3	5	5	3	3	0	2	2	2	2	2	8	3	6	6
Z22	3	4	5	3	3	2	0	1	2	3	3	8	4	5	5
Z23	2	4	4	2	2	2	1	0	2	2	3	8	4	4	5
Z24	2	3	3	1	1	2	2	2	0	1	2	8	5	5	5
Z25	2	4	4	2	2	2	3	2	1	0	1	8	5	5	6
Z26	3	5	5	3	3	2	3	3	2	1	0	8	5	6	6
Z27	8	8	8	8	8	8	8	8	8	8	8	0	8	8	8
Z28	5	7	7	5	5	3	4	4	5	5	5	8	0	8	8
Z29	4	3	4	4	4	6	5	4	5	5	6	8	8	0	1
Z30	5	3	5	5	4	6	5	5	5	6	6	8	8	1	0
Z31	4	2	3	4	4	6	5	4	4	5	6	8	8	1	2

Z32	3	3	4	3	3	5	3	3	4	4	5	8	6	2	2
Z33	4	4	5	4	3	4	3	3	4	4	5	7	5	3	3
Z34	1	1	2	1	1	4	3	2	2	3	4	8	6	3	4
Z35	2	1	2	2	2	4	4	3	3	4	4	8	7	3	3
Z36	8	6	8	8	7	8	8	8	8	8	8	7	8	4	3
Z37	2	1	1	2	2	4	4	3	3	3	4	8	7	3	3
Z38	3	2	3	3	3	5	4	4	4	5	5	8	7	2	2
Z39	6	5	6	6	6	7	6	6	6	7	8	7	8	3	3
Z40	5	3	4	5	5	7	7	6	6	6	7	8	8	3	3
Z41	3	5	5	3	3	2	4	3	2	2	1	8	5	6	7

	+Z31	Z32	Z33	Z34	Z35	Z36	Z37	Z38	Z39	Z40	Z41
Z1	4	3	3	2	3	2	3	4	6	5	2
Z2	8	7	6	6	7	8	6	8	8	8	3
Z3	8	8	8	7	8	8	8	8	8	8	4
Z4	8	8	7	7	7	8	7	8	8	8	4
Z5	8	8	8	7	8	8	8	8	8	8	4
Z6	7	6	5	5	5	8	5	6	8	8	2
Z7	7	6	6	5	6	8	6	7	8	8	2
Z8	7	6	5	5	5	8	5	6	8	8	2
Z9	4	3	3	2	3	8	2	4	6	5	2
Z10	4	4	4	2	3	8	3	4	6	6	2
Z11	4	4	4	1	2	8	2	4	7	5	3
Z12	4	3	3	2	3	7	3	3	5	5	3
Z13	3	3	4	1	1	7	1	3	6	4	4
Z14	3	3	4	2	1	7	1	3	6	3	5
Z15	3	3	4	1	1	7	1	3	6	4	4
Z16	4	3	4	1	2	8	2	3	6	5	3
Z17	2	3	4	1	1	6	1	2	5	3	5
Z18	3	4	5	2	2	8	1	3	6	4	5
Z19	4	3	4	1	2	8	2	3	6	5	3
Z20	4	3	3	1	2	7	2	3	6	5	3
Z21	6	5	4	4	4	8	4	5	7	7	2
Z22	5	3	3	3	4	8	4	4	6	7	4
Z23	4	3	3	2	3	8	3	4	6	6	3
Z24	4	4	4	2	3	8	3	4	6	6	2
Z25	5	4	4	3	4	8	3	5	7	6	2
Z26	6	5	5	4	4	8	4	5	8	7	1
Z27	8	8	7	8	8	7	8	8	7	8	8
Z28	8	6	5	6	7	8	7	7	8	8	5
Z29	1	2	3	3	3	4	3	2	3	3	6
Z30	2	2	3	4	3	3	3	2	3	3	7
Z31	0	2	3	3	2	5	2	1	4	3	6
Z32	2	0	2	3	3	5	3	2	3	4	5
Z33	3	2	0	4	4	6	4	3	4	5	6

Z34	3	3	4	0	1	7	1	2	6	4	4
Z35	2	3	4	1	0	6	1	2	5	3	5
Z36	5	5	6	7	6	0	6	5	2	5	8
Z37	2	3	4	1	1	6	0	2	5	3	5
Z38	1	2	3	2	2	5	2	0	4	3	6
Z39	4	3	4	6	5	2	5	4	0	5	8
Z40	3	4	5	4	3	5	3	3	5	0	7
Z41	6	5	6	4	5	8	5	6	8	7	0

```
*PARAMETER TTE(X,X1)  activity time for tractors with empty trailers  ;
*              going from area X to area X1 (includes running time,
*              hitching/unhitching time, and time to process paperwork)
*TTE(X,X1) = TTF(X,X1) ;
*PARAMETER TTB(X,X1)  activity time for bobtailing tractors  ;
*              going from area X to area X1 (includes running time,
*              hitching/unhitching time).
*TTB(X,X1) = TTF(X,X1) ;
PARAMETERS
 TCACTIVITY(X,T)  equals 1 if there could be tractor activity at area X;
*            at time T
TCACTIVITY(X,T)$((SAMEDAY(T-TT(X,'z1'),T+(TT(X,'z1')-1))) AND
  (ORD(T)-1-WINDEX(T)-TT(X,'z1') GE 0) AND (TT(X,'z1') LT 5))=1;
TCACTIVITY(X,T)$((TT(X,'z1') GE 5) AND (ORD(T)-1-WINDEX(T) GE TT(X,'z1'))
  AND (ORD(T)-WINDEX(T)-1 LE TT(X,'z1')+2))=1;
TCACTIVITY('z1',T)=0;
*display TCACTIVITY;
PARAMETER EXDEPART(X,T)  equals 1 if trailer can leave area X at time T;
*               empty but not full
EXDEPART(X,T)$((TT('z1',X) GE 5) AND (ORD(T)-1-WINDEX(T) EQ
TT('z1',X)+TRACTTIME))=1;
```

```
*display EXDEPART;

PARAMETERS DEPART(X,X1,T)  equals 1 if a bobtailed tractor or tractor-trailer;

*                  can depart area X for area X1 at time T

DEPART(X,X1,T)=1$(ORD(T)-WINDEX(T)-1 GE TT('z1',X) AND ORD(T)-

WINDEX(T)-1

LE 10-TT(X,X1)-TT(X1,'z1'));

DEPART('z1',X1,T)=1$SAMEDAY(T,T+(2*TT(X1,'z1')-1));

DEPART(X,'z1',T)=SAMEDAY(T-TT('z1',X),T+(TT('z1',X)-1))$(((ORD(T)-

1-WINDEX(T)-TT('z1',X)) GE 0) AND (TT('z1',X) LT 5));

DEPART('z1',X,T)$((TT('z1',X) GE 5) AND (ORD(T)-1 EQ WINDEX(T)))=1;

DEPART(X,'z1',T)$((TT(X,'z1') GE 5) AND (ORD(T)-1-WINDEX(T) GE TT(X,'z1'))

AND (ORD(T)-1-WINDEX(T) LE TT(X,'Z1')+2))=1;

DEPART(X,X,T)=0;
```

TABLE CDEMANDS(X,T) loads to be delivered to A at T

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140
z2	1	1													
z3	2														
z4											1				
z5			4	8							2				
z6						3							2		
z7	1		1					1	2	1					
z8							2		2						
z9	1		8			11		4		1	2		1		
z10	3	1		6				1	2		4	4		1	
z11	1														
z12						2									
z13	4	3		1	4	2	2		10	2					
z14						1									
z15								1							
z16	1		1		2										
z17	6			3	2	13	3			6		4	17		6
z18	1														
z19					2					1					
z20	2														
z21	2														
z22		1	2	2		1					1				

z23		1		2											
z24						1			1						
z25	3								2				2		
z26	1														
z27	1														
z28	2			2				2			2		1		
z29															
z30										2	2				
z31		1						1							
z32															
z33	3														
z34									1				2		
z35															
z36															
z37	1					2			2		2				
z38										1					
z39															
z40										1					
z41											1		2	;	

TABLE SDEMANDS(X,T) loads to be picked up at X at time T

	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140
z2	2		1					1			1				
z3		1					1					1			
z4															
z5															
z6													1		
z7		1													
z8														1	
z9					2	2									
z10											1	1			
z11															
z12															
z13			1												
z14	1			1	1			3		2	1		1		
z15															
z16															
z17															
z18		1													
z19															
z20															
z21															
z22															
z23															

z24	1							1						
z25	1	1			1	1	1							
z26														
z27														
z28														
z29														1
z30														
z31														
z32							1							
z33														
z34														
z35	1													
z36												1		
z37														
z38														
z39														
z40														
z41														

PARAMETER CB(A) hourly rate for tractor idling at area A;

CB(A)=25;

CB('z1')=0;

TABLE CF(A,X) one-way rates for loaded movements between terminal and areas

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
Z1		284	326	296	325	217	248	202	94	102	135	122	163	225	149
Z2	84														
Z3	326														
Z4	296														
Z5	325														
Z6	217														
Z7	248														
Z8	202														
Z9	94														
Z10	102														
Z11	135														
Z12	122														
Z13	163														
Z14	225														
Z15	149														
Z16	130														
Z17	205														
Z18	106														

Z19	122
Z20	120
Z21	159
Z22	160
Z23	136
Z24	102
Z25	127
Z26	162
Z27	104
Z28	261
Z29	272
Z30	276
Z31	247
Z32	227
Z33	229
Z34	164
Z35	207
Z36	164
Z37	189
Z38	244
Z39	341
Z40	314
Z41	184

	+Z16	z17	z18	z19	z20	z21	z22	z23	z24	z25	z26	z27	z28	z29	z30
Z1	130	205	106	122	120	159	160	136	102	127	162	104	261	272	276
Z2															
Z3															
Z4															
Z5															
Z6															
Z7															
Z8															
Z9															
Z10															
Z11															
Z12															
Z13															
Z14															
Z15															
Z16															
Z17															
Z18															
Z19															
Z20															

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Z34
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Z36
Z37
Z38
Z39
Z40
Z41

	+Z31	Z32	Z33	Z34	Z35	Z36	Z37	Z38	Z39	Z40	Z41
Z1	247	227	229	164	207	164	189	244	341	314	184
Z2											
Z3											
Z4											
Z5											
Z6											
Z7											
Z8											
Z9											
Z10											
Z11											
Z12											
Z13											
Z14											
Z15											
Z16											
Z17											
Z18											
Z19											
Z20											
Z21											
Z22											

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Z37
Z38
Z39
Z40
Z41

TABLE CE(A,X) one-way rates for empty movements between areas A and X

	Z1	Z2	Z3	Z4	Z5	Z6	Z7	Z8	Z9	Z10	Z11	Z12	Z13	Z14	Z15
Z1	0	240	283	252	282	174	204	158	50	58	92	78	120	182	105
Z2	240	0	161	145	110	96	74	94	215	204	263	243	291	337	270
Z3	283	161	0	66	194	170	149	161	278	267	324	306	354	400	333
Z4	252	145	66	0	177	149	130	140	256	245	303	285	331	378	312
Z5	282	110	194	177	0	160	138	158	279	268	326	308	355	401	334
Z6	174	96	170	149	160	0	66	52	163	151	210	192	238	284	219
Z7	204	74	149	130	138	66	0	65	185	174	232	214	260	308	241
Z8	158	94	161	140	158	52	65	0	166	155	212	194	241	287	221
Z9	50	215	278	256	279	163	185	166	0	59	93	82	121	168	102
Z10	58	204	267	245	268	151	174	155	59	0	108	84	137	183	117
Z11	92	263	324	303	326	210	232	212	93	108	0	124	92	138	81
Z12	78	243	306	285	308	192	214	194	82	84	124	0	128	176	108
Z13	120	291	354	331	355	238	260	241	121	137	92	128	0	93	64
Z14	182	337	400	378	401	284	308	287	168	183	138	176	93	0	112
Z15	105	270	333	312	334	219	241	221	102	117	81	108	64	112	0
Z16	86	250	313	292	314	197	221	201	82	96	90	103	88	136	68
Z17	161	330	393	370	394	277	300	281	160	176	131	168	85	75	104
Z18	63	334	397	376	399	282	305	285	166	181	133	174	101	76	109
Z19	78	246	309	286	310	193	215	196	76	92	85	100	88	134	68
Z20	76	245	308	199	309	192	215	195	76	91	88	79	99	147	78
Z21	115	146	220	256	210	93	115	102	119	108	165	147	194	240	174
Z22	117	203	277	283	255	150	173	159	121	106	170	113	190	237	169

Z23	93	231	304	245	286	178	201	437	91	85	139	73	148	196	128
Z24	58	204	267	250	269	152	175	155	63	66	109	99	137	184	118
Z25	84	184	246	223	249	133	155	134	84	88	125	122	156	202	137
Z26	119	165	225	203	233	113	134	114	118	114	161	155	192	238	173
Z27	60	485	602	585	229	514	538	523	474	476	508	440	491	194	478
Z28	218	160	277	260	472	193	183	202	237	222	285	246	313	360	294
Z29	229	394	457	434	139	341	364	345	224	237	233	204	187	184	196
Z30	232	411	474	452	445	359	382	361	242	255	254	221	208	203	217
Z31	203	383	414	423	463	330	352	332	213	225	200	195	152	148	163
Z32	184	345	421	392	436	292	314	301	182	193	201	157	167	183	170
Z33	185	310	383	363	384	257	279	265	184	186	219	150	201	225	188
Z34	121	284	347	324	348	231	254	234	114	130	92	121	50	101	57
Z35	164	323	386	364	387	270	293	274	154	169	129	158	81	82	95
Z36	121	543	610	587	577	491	513	496	377	390	388	356	342	338	351
Z37	146	308	370	348	372	255	277	258	138	154	115	143	68	79	79
Z38	201	368	431	410	422	315	339	319	200	212	188	181	141	145	151
Z39	297	451	524	504	490	399	421	406	301	303	327	267	287	284	296
Z40	270	437	500	478	501	403	408	387	268	283	242	273	195	175	210
Z41	140	161	222	201	225	111	132	112	134	137	184	177	214	261	195

	+Z16	Z17	Z18	Z19	Z20	Z21	Z22	Z23	Z24	Z25	Z26	Z27	Z28	Z29	Z30
Z1	86	161	63	78	76	115	117	93	58	84	119	60	218	229	232
Z2	250	330	334	246	245	146	203	231	204	184	165	485	160	394	411
Z3	313	393	397	309	308	220	277	304	267	246	225	602	277	457	474
Z4	292	370	376	286	199	256	283	245	250	223	203	585	260	434	452
Z5	314	394	399	310	309	210	255	286	269	249	233	229	472	139	445
Z6	197	277	282	193	192	93	150	178	152	133	113	514	193	341	359
Z7	221	300	305	215	215	115	173	201	175	155	134	538	183	364	382
Z8	201	281	285	196	195	102	159	437	155	134	114	523	202	345	361
Z9	82	160	166	76	76	119	121	91	63	84	118	474	237	224	242
Z10	96	176	181	92	91	108	106	85	66	88	114	476	222	237	255
Z11	90	131	133	85	88	165	170	139	109	125	161	508	285	233	254
Z12	103	168	174	100	79	147	113	73	99	122	155	440	246	204	221
Z13	88	85	101	88	99	194	190	148	137	156	192	491	313	187	208
Z14	136	75	76	134	147	240	237	196	184	202	238	194	360	184	203
Z15	68	104	109	68	78	174	169	128	118	137	173	478	294	196	217
Z16	0	128	132	48	67	154	159	123	97	117	152	486	274	221	240
Z17	128	0	102	128	139	233	228	188	176	195	231	508	352	165	184
Z18	132	102	0	132	143	238	234	193	182	199	234	539	358	214	234
Z19	48	128	132	0	64	149	155	120	93	112	148	483	268	220	237
Z20	67	139	143	64	0	148	141	100	92	114	147	463	268	200	217
Z21	154	233	238	149	148	0	101	128	109	121	122	477	184	297	314
Z22	159	228	234	155	141	101	0	85	127	146	173	428	186	247	265
Z23	123	188	193	120	100	128	85	0	103	129	156	439	218	218	234
Z24	97	176	182	93	92	109	127	103	0	73	103	491	237	241	258

Z25	117	195	199	112	114	121	146	129	73	0	79	514	256	263	281
Z26	152	231	234	148	147	122	173	156	103	79	0	547	249	296	313
Z27	486	508	539	483	463	477	428	439	491	514	547	0	381	414	419
Z28	274	352	358	268	268	184	186	218	237	256	249	381	0	375	393
Z29	221	165	214	220	200	297	247	218	241	263	296	414	375	0	64
Z30	240	184	234	237	217	314	265	234	258	281	313	419	393	64	0
Z31	187	130	181	187	187	286	238	208	229	251	284	447	367	91	111
Z32	179	157	200	176	156	242	185	167	197	220	252	394	314	110	128
Z33	196	213	239	194	174	208	150	159	202	225	257	356	270	167	185
Z34	81	92	108	82	92	187	182	140	131	150	186	484	306	185	205
Z35	120	56	106	121	130	227	217	178	169	190	225	501	345	157	177
Z36	375	319	369	372	351	441	384	369	393	415	448	365	487	199	181
Z37	104	70	94	105	114	211	202	164	154	174	210	490	330	165	185
Z38	176	119	169	176	174	272	224	194	215	238	270	450	352	101	121
Z39	305	265	315	302	282	349	292	277	319	342	374	332	401	149	149
Z40	234	160	208	234	245	340	327	292	284	303	339	514	455	143	150
Z41	175	254	258	170	169	120	195	178	125	110	90	569	247	319	336

	+Z31	Z32	Z33	Z34	Z35	Z36	Z37	Z38	Z39	Z40	Z41
Z1	203	184	185	121	164	121	146	201	297	270	140
Z2	383	345	310	284	323	543	308	368	451	437	161
Z3	414	421	383	347	386	610	370	431	524	500	222
Z4	423	392	363	324	364	587	348	410	504	478	201
Z5	463	436	384	348	387	577	372	422	490	501	225
Z6	330	292	257	231	270	491	255	315	399	403	111
Z7	352	314	279	254	293	513	277	339	421	408	132
Z8	332	301	265	234	274	496	258	319	406	387	112
Z9	213	182	184	114	154	377	138	200	301	268	134
Z10	225	193	186	130	169	390	154	212	303	283	137
Z11	200	201	219	92	129	388	115	188	327	242	184
Z12	195	157	150	121	158	356	143	181	267	273	177
Z13	152	167	201	50	81	342	68	141	287	195	214
Z14	148	183	225	101	82	338	79	145	284	175	261
Z15	163	170	188	57	95	351	79	151	296	210	195
Z16	187	179	196	81	120	375	104	176	305	234	175
Z17	130	157	213	92	56	319	70	119	265	160	254
Z18	181	200	239	108	106	369	94	169	315	208	258
Z19	187	176	194	82	121	372	105	176	302	234	170
Z20	187	156	174	92	130	351	114	174	282	245	169
Z21	286	242	208	187	227	441	211	272	349	340	120
Z22	238	185	150	182	217	384	202	224	292	327	195
Z23	208	167	159	140	178	369	164	194	277	292	178
Z24	229	197	202	131	169	393	154	215	319	284	125
Z25	251	220	225	150	190	415	174	238	342	303	110
Z26	284	252	257	186	225	448	210	270	374	339	90

Z27	447	394	356	484	501	365	490	450	332	514	569
Z28	367	314	270	306	345	487	330	352	401	455	247
Z29	91	110	167	185	157	199	165	101	149	143	319
Z30	111	128	185	205	177	181	185	121	149	150	336
Z31	0	120	176	150	122	246	130	69	192	150	306
Z32	120	0	106	160	149	263	149	110	175	211	275
Z33	176	106	0	194	203	290	188	173	197	267	279
Z34	150	160	194	0	83	340	67	139	285	196	209
Z35	122	149	203	83	0	312	59	112	258	158	248
Z36	246	263	290	340	312	0	320	256	136	245	470
Z37	130	149	188	67	59	320	0	119	265	174	232
Z38	69	110	173	139	112	256	119	0	202	163	293
Z39	192	175	197	285	258	136	265	202	0	249	396
Z40	150	211	267	196	158	245	174	163	249	0	361
Z41	306	275	279	209	248	470	232	293	396	361	0

```
sdem(a)=sum(r,sdemands(a,r));

cdem(a)=sum(r,cdemands(a,r));

cdem('z1')=1;

sdem('z1')=1;

tract(a,t)=sum(r$((windex(t)-20 le ord(r)-1) and (ord(r)-1 le windex(t)))

,(sdemands(a,r)+cdemands(a,r)));


PARAMETER REQUEST(T);

REQUEST(T)$((ORD(T)-1-10*FLOOR((ORD(T)-1)/10)) EQ 0)=1;

PARAMETER INDEX(T) ;

INDEX(T) = ORD(T) - 1 ;

PARAMETER AREAINDEX(X) ;

AREAINDEX(X) = ORD(X) - 1 ;

PARAMETER RDEPART(R,T) pairings of load availability and departure times;

RDEPART(R,T)=SAMEDAY(R,T+(FLOOR((ORD(T)-ORD(R))/TIMEWINDOW)-

ORD(T)+ORD(R)))$((ORD(R)-1) EQ 10*FLOOR((ORD(R)-1)/10));

RDEPART(R,'150')=0;
```

```
PARAMETER TRFLOWOUT(A,S,T) flow conservation for loaded trailers (OUT) ;
*                   at areas at time T. Trailers
*                   departed from terminal at time S
TRFLOWOUT(A,S,T)=SAMEDAY(S,T)$((ORD(T)-ORD(S) EQ
TT(A,'z1')+TRACTTIME)
AND (TT('z1',A) LT 5));
TRFLOWOUT(A,S,T)$((ORD(T)-1-WINDEX(T) EQ 9) AND (TT(A,'z1') EQ 4)AND
SAMEDAY(S,T) AND ((ORD(T)-ORD(S) EQ TT(A,'z1')+TRACTTIME)))=0;
TRFLOWOUT(A,S,T)$((TT(A,'z1') GE 5) AND (ORD(T)-ORD(S) EQ TT(A,'z1')+ 2)
AND SAMEDAY(T,S) AND (ORD(S)-1 EQ WINDEX(S))))=1;
TRFLOWOUT(A,S,T)$((ORD(T)-ORD(S) EQ TT(A,'Z1')+2) AND ((TT(A,'Z1') EQ 2)
OR (TT(A,'Z1') EQ 1)) AND (SAMEDAY(S,T-1)))=1;
TRFLOWOUT(A,S,T)$((ORD(T)-ORD(S) EQ 2) AND (TT(A,'Z1') EQ 1) AND
SAMEDAY(S,T-1) AND (ORD(T)-1 EQ WINDEX(T)))=1;
TRFLOWOUT('z1',S,T)=0;
PARAMETER TRFLOWIN(A,S,T) flow conservation for loaded trailers (IN);
*                   to terminal at time T. Trailers departed from
*                   area at time S.
TRFLOWIN(A,S,T)$((ORD(S)-ORD(T) EQ TRACTTIME) AND (ORD(S)-1-
WINDEX(S) GE TT(A,'Z1')) AND (ORD(S)-1-WINDEX(S)+TT(A,'Z1') LE 10) AND
(WINDEX(S) EQ WINDEX(T)) AND SAMEDAY(S,T))=1;
TRFLOWIN(A,S,T)$((TT(A,'z1') LT TRACTTIME) AND (ORD(S)-1-WINDEX(S) LE
TT('z1',A)) AND (ORD(T)-1 EQ WINDEX(T)) AND (ORD(S)-1 NE WINDEX(S))
AND SAMEDAY(S,T))=1;
TRFLOWIN(A,S,T)$((ORD(S)-1-WINDEX(S) EQ TT(A,'z1')) AND (TT(A,'z1') GE 5)
AND (ORD(S)-ORD(T) EQ TRACTTIME) AND SAMEDAY(S,T))=1;
TRFLOWIN('z1',S,T)=0;
```

```
PARAMETER IDLETIME(A,T) areas paired with times T tractors could be idle ;
*              note: this predicate is associated with variable b(A,A,T)
     IDLETIME(A,T)$((SAMEDAY(T-TT('z1',A),T+TT(A,'z1'))))=1;
     IDLETIME(A,T)$((TT(A,'Z1') GE 5) AND (ORD(T)-1-WINDEX(T) GE
TT(A,'Z1') AND (ORD(T)-1-WINDEX(T) LE TT(A,'Z1')+1)))=1;
     IDLETIME('z1',T)=0;
PARAMETER TRSUPPLY(A)  number of empty trailers at area A at time/
z4=1
z5=7
z6=2
z7=4
z8=1
z9=12
z10=13
z11=1
z12=1
z13=20
z15=1
z16=3
z17=32
z19=2
z20=2
z21=2
z22=4
z23=2
z24=1
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z26=1
z27=1
z28=8
z30=2
z31=2
z33=3
z37=4
z38=1
z39=1
z40=1
z41=2 /;
PARAMETER  AREA(A)  all areas excluding terminal Z1 /
  (z2*z41) = 1 / ;
PARAMETER NETREPORT(*,*,*,*)  output report ;
OPTION NETREPORT:2:0:1 ;

VARIABLES
  OUT(X,T,R)  loads available at R from terminal to area X departing at T
  IN(X,T,R)   loads available at R from area X to terminal departing at T
  TOTALCOST   cost of objective function
  E(X,X1,T)   empty trailers from area X to area X1, departing at time T
  B(X,X1,T)   bobtailing tractors from area X to area X1, departing at time T
*           note: B(X,X,T) also designates the idle tractors at area A at T
  EE(A,T)     empty trailers at area X during period T to T + 1  ;
POSITIVE VARIABLES E,B,EE,OUT,IN ;

EQUATIONS
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```
 COSTEQ2C      Centralized Operations Planning with Plan C
*              loaded movements between terminal and areas, tractor idling,
*              at areas, deadheading and tractor bobtailing between areas.
 DELIVERY(X,R)  service constraint on deliveries of loads to consignees
 PICKUP(A,R)    service constraint on pick ups of loads from shippers
 TRACTOR(A,T)   tractor flow conservation at areas
 TRAILER(A,T)   trailer flow conservation at areas
 EMPTY          balance empty trailer movements between terminal and areas.
 BOBTAILS       balance bobtails between areas and terminal ;

BOBTAILS.. SUM((A,T)$(AREA(A) AND DEPART('z1',A,T)), B('z1',A,T))
   =E= SUM((A,T)$(AREA(A) AND DEPART(A,'z1',T)), B(A,'z1',T)) ;
EMPTY.. SUM((A,T)$(AREA(A) and DEPART(A,'z1',T) and cdem(a)), E(A,'z1',T))
  - SUM((A,T)$(AREA(A) and DEPART('z1',A,T) and sdem(a)), E('z1',A,T)) =G= 0 ;
COSTEQ2C.. TOTALCOST =E= SUM((R,X,T)$(REQUEST(R) and
DEPART('z1',X,T) and RDEPART(R,T) and cdemands(x,r)),CF('z1',X) * OUT(X,T,R))
    + SUM((R1,X1,T1)$(REQUEST(R1) and DEPART(X1,'z1',T1) and
RDEPART(R1,T1) and (not EXDEPART(X1,T1)) and sdemands(x1,r1)),
  CF(X1,'z1') * IN(X1,T1,R1)) + SUM((A,X,T)$(DEPART(A,X,T) and cdem(a) and
sdem(x)), CE(A,X) * E(A,X,T)) + SUM((A,T)$(IDLETIME(A,T) and tract(a,t)),CB(A)
* B(A,A,T) ) + SUM((A,X,T)$(DEPART(A,X,T)), CE(A,X) * B(A,X,T) ) ;
DELIVERY(A,R)$(AREA(A) and REQUEST(R) and cdemands(a,r))..
  SUM(T$(RDEPART(R,T) AND DEPART('z1',A,T)), OUT(A,T,R)) =E=
CDEMANDS(A,R) ;
PICKUP(A,R)$(AREA(A) and REQUEST(R) and sdemands(a,r))..
  SUM(T$(RDEPART(R,T) and DEPART(A,'z1',T) and (not EXDEPART(A,T))),
IN(A,T,R)) =E= SDEMANDS(A,R) ;
```

```
TRACTOR(A,T)$(AREA(A) and TCACTIVITY(A,T))..
SUM((T1,R)$(RDEPART(R,T1) and DEPART('z1',A,T1) and (INDEX(T1) + TT('z1',A)
eq INDEX(T)) and cdemands(a,r)) , OUT(A,T1,R)) + SUM((X,T2)$(DEPART(X,A,T2)
and (INDEX(T2) + TT(X,A) eq INDEX(T)) and cdem(x) and sdem(a)),E(X,A,T2)) +
SUM((X,T2)$(DEPART(X,A,T2) and (INDEX(T2) + TT(X,A) eq INDEX(T)))
,B(X,A,T2)) + SUM(T1$( (INDEX(T1) eq INDEX(T) - 1) and IDLETIME(A,T1) and
tract(a,t1)) , B(A,A,T1)) =E= SUM(R1$(RDEPART(R1,T) and DEPART(A,'z1',T) and
(not EXDEPART(A,T)) and sdemands(a,r1)), IN(A,T,R1)) +
SUM(X1$(DEPART(A,X1,T) and cdem(a) and sdem(x1)), E(A,X1,T)) +
SUM(X1$(DEPART(A,X1,T)) ,B(A,X1,T))+ B(A,A,T)$(IDLETIME(A,T) and
tract(a,t));
TRAILER(A,T)$AREA(A)..
  SUM((R,S)$(RDEPART(R,S) and TRFLOWOUT(A,S,T) and cdemands(a,r))
,OUT(A,S,R)) + SUM((S,X)$(DEPART(X,A,S) and (AREAINDEX(X) ne
AREAINDEX(A)) and (INDEX(T) eq TT(X,A) + INDEX(S)) and SAMEDAY(T,S) and
cdem(x) and sdem(a)), E(X,A,S)) + TRSUPPLY(A)$FPERIOD(T) +
SUM(T2$((INDEX(T2) eq INDEX(T) - 1)) , EE(A,T2)) =E= IN(A,S,R)) +
SUM(X$(DEPART(A,X,T) and (AREAINDEX(X) ne AREAINDEX(A)) and cdem(a)
and sdem(x)), E(A,X,T)) + EE(A,T);
EE.fx(A,'150')$AREA(A) = TRSUPPLY(A) ;
EE.fx(A,'0')$AREA(A) = TRSUPPLY(A) ;
OUT.FX('Z2','0','0')=   1.00;
OUT.FX('Z2','30','10')=  1.00;
OUT.FX('Z3','10','0')=   1.00;
OUT.FX('Z3','20','0')=   1.00;
OUT.FX('Z4','120','100')= 1.00;
OUT.FX('Z5','20','20')=  4.00;
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OUT.FX('Z5','30','30')=  7.00;
OUT.FX('Z5','50','30')=  1.00;
OUT.FX('Z5','100','100')= 2.00;
OUT.FX('Z6','51','50')=  2.00;
OUT.FX('Z6','63','50')=  1.00;
OUT.FX('Z6','121','120')= 1.00;
OUT.FX('Z6','123','120')= 1.00;
OUT.FX('Z7','12','0')=   1.00;
OUT.FX('Z7','22','20')=  1.00;
OUT.FX('Z7','70','70')=  1.00;
OUT.FX('Z7','80','80')=  1.00;
OUT.FX('Z7','90','90')=  1.00;
OUT.FX('Z7','100','80')=  1.00;
OUT.FX('Z8','64','60')=  1.00;
OUT.FX('Z8','71','60')=  1.00;
OUT.FX('Z8','83','80')=  1.00;
OUT.FX('Z8','93','80')=  1.00;
OUT.FX('Z9','23','0')=   1.00;
OUT.FX('Z9','31','20')=  8.00;
OUT.FX('Z9','50','50')=  2.00;
OUT.FX('Z9','57','50')=  7.00;
OUT.FX('Z9','64','50')=  2.00;
OUT.FX('Z9','90','90')=  1.00;
OUT.FX('Z9','91','70')=  4.00;
OUT.FX('Z9','121','100')= 2.00;
OUT.FX('Z9','132','120')= 1.00;
OUT.FX('Z10','1','0')=   3.00;
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OUT.FX('Z10','12','10')=  1.00;
OUT.FX('Z10','42','30')=  6.00;
OUT.FX('Z10','95','70')=  1.00;
OUT.FX('Z10','100','80')=  2.00;
OUT.FX('Z10','104','100')= 1.00;
OUT.FX('Z10','105','100')= 3.00;
OUT.FX('Z10','115','110')= 4.00;
OUT.FX('Z10','143','130')= 1.00;
OUT.FX('Z11','15','0')=   1.00;
OUT.FX('Z12','51','50')=  1.00;
OUT.FX('Z12','53','50')=  1.00;
OUT.FX('Z13','12','0')=   4.00;
OUT.FX('Z13','33','30')=  1.00;
OUT.FX('Z13','34','10')=  3.00;
OUT.FX('Z13','40','40')=  4.00;
OUT.FX('Z13','76','50')=  2.00;
OUT.FX('Z13','76','60')=  2.00;
OUT.FX('Z13','85','80')= 10.00;
OUT.FX('Z13','91','90')=  2.00;
OUT.FX('Z14','51','50')=  1.00;
OUT.FX('Z15','76','70')=  1.00;
OUT.FX('Z16','2','0')=   1.00;
OUT.FX('Z16','32','20')=  1.00;
OUT.FX('Z16','63','40')=  2.00;
OUT.FX('Z17','0','0')=   5.00;
OUT.FX('Z17','10','0')=   1.00;
OUT.FX('Z17','31','30')=  1.00;
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OUT.FX('Z17','30','30')=  2.00;
OUT.FX('Z17','40','40')=  1.00;
OUT.FX('Z17','41','40')=  1.00;
OUT.FX('Z17','61','60')=  1.00;
OUT.FX('Z17','70','60')=  1.00;
OUT.FX('Z17','71','50')= 12.00;
OUT.FX('Z17','73','50')=  1.00;
OUT.FX('Z17','80','60')=  1.00;
OUT.FX('Z17','90','90')=  1.00;
OUT.FX('Z17','92','90')=  1.00;
OUT.FX('Z17','100','90')=  3.00;
OUT.FX('Z17','101','90')=  1.00;
OUT.FX('Z17','120','120')=17.00;
OUT.FX('Z17','130','110')= 4.00;
OUT.FX('Z17','140','140')= 6.00;
OUT.FX('Z18','7','0')=   1.00;
OUT.FX('Z19','50','40')=  2.00;
OUT.FX('Z19','114','90')=  1.00;
OUT.FX('Z20','14','0')=   2.00;
OUT.FX('Z21','23','0')=   2.00;
OUT.FX('Z22','13','10')=  1.00;
OUT.FX('Z22','43','20')=  2.00;
OUT.FX('Z22','53','30')=  2.00;
OUT.FX('Z22','63','50')=  1.00;
OUT.FX('Z22','113','100')= 1.00;
OUT.FX('Z23','13','10')=  1.00;
OUT.FX('Z23','46','30')=  2.00;
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OUT.FX('Z24','57','50')=  1.00;
OUT.FX('Z24','97','80')=  1.00;
OUT.FX('Z25','21','0')=   1.00;
OUT.FX('Z25','23','0')=   1.00;
OUT.FX('Z25','28','0')=   1.00;
OUT.FX('Z25','80','80')=  1.00;
OUT.FX('Z25','84','80')=  1.00;
OUT.FX('Z25','120','120')= 1.00;
OUT.FX('Z25','122','120')= 1.00;
OUT.FX('Z26','3','0')=   1.00;
OUT.FX('Z27','26','0')=   1.00;
OUT.FX('Z28','0','0')=   2.00;
OUT.FX('Z28','40','30')=  2.00;
OUT.FX('Z28','80','70')=  2.00;
OUT.FX('Z28','110','100')= 2.00;
OUT.FX('Z28','140','120')= 1.00;
OUT.FX('Z30','90','90')=  1.00;
OUT.FX('Z30','100','90')=  1.00;
OUT.FX('Z30','120','100')= 2.00;
OUT.FX('Z31','20','10')=  1.00;
OUT.FX('Z31','80','70')=  1.00;
OUT.FX('Z33','20','0')=   3.00;
OUT.FX('Z34','106','80')=  1.00;
OUT.FX('Z34','120','120')= 1.00;
OUT.FX('Z34','130','120')= 1.00;
OUT.FX('Z37','0','0')=   1.00;
OUT.FX('Z37','60','50')=  2.00;
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OUT.FX('Z37','80','80')= 2.00;
OUT.FX('Z37','120','100')= 2.00;
OUT.FX('Z38','102','90')= 1.00;
OUT.FX('Z40','90','90')= 1.00;
OUT.FX('Z41','106','100')= 1.00;
OUT.FX('Z41','136','120')= 2.00;
IN.FX('Z2','15','0')= 1.00;
IN.FX('Z2','25','0')= 1.00;
IN.FX('Z2','35','20')= 1.00;
IN.FX('Z2','85','70')= 1.00;
IN.FX('Z2','105','90')= 1.00;
IN.FX('Z3','26','10')= 1.00;
IN.FX('Z3','66','60')= 1.00;
IN.FX('Z3','126','100')= 1.00;
IN.FX('Z6','124','110')= 1.00;
IN.FX('Z7','26','10')= 1.00;
IN.FX('Z8','127','120')= 1.00;
IN.FX('Z9','51','50')= 2.00;
IN.FX('Z9','65','40')= 2.00;
IN.FX('Z10','101','100')= 1.00;
IN.FX('Z10','105','90')= 1.00;
IN.FX('Z13','42','20')= 1.00;
IN.FX('Z14','6','0')= 1.00;
IN.FX('Z14','45','30')= 1.00;
IN.FX('Z14','65','40')= 1.00;
IN.FX('Z14','74','70')= 1.00;
IN.FX('Z14','77','70')= 1.00;
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IN.FX('Z14','87','80')=  1.00;
IN.FX('Z14','94','70')=  1.00;
IN.FX('Z14','105','80')=  1.00;
IN.FX('Z14','115','90')=  1.00;
IN.FX('Z14','124','110')= 1.00;
IN.FX('Z18','11','10')=  1.00;
IN.FX('Z24','9','0')=   1.00;
IN.FX('Z24','98','70')=  1.00;
IN.FX('Z25','21','0')=   1.00;
IN.FX('Z25','29','10')=  1.00;
IN.FX('Z25','68','40')=  1.00;
IN.FX('Z25','77','50')=  1.00;
IN.FX('Z25','81','60')=  1.00;
IN.FX('Z29','126','120')= 1.00;
IN.FX('Z32','67','60')=  1.00;
IN.FX('Z35','6','0')=   1.00;
IN.FX('Z36','108','100')= 1.00;
*---------------------------------------------------------------------------
* The model COPLP yields a real valued solution for decision variables. Because of the
 model's near network structure some of the variables are likely to be integers.
*---------------------------------------------------------------------------
MODEL COPLP
/COSTEQ2C,PICKUP,DELIVERY,TRACTOR,TRAILER,EMPTY,BOBTAILS /;
SOLVE COPLP MINIMIZING TOTALCOST USING LP ;
* establish the report and calculate total tractor hours
* Alternative 2a ***
NETREPORT('Total','cost','3day','2a') =
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  SUM((R,X,T)$DEPART('z1',X,T), CF('z1',X) * OUT.l(X,T,R)) +
SUM((R,X,T)$DEPART(X,'z1',T),  CF(X,'z1') * IN.l(X,T,R)) +
SUM((A,T)$DEPART(A,'z1',T), CE(A,'z1') * E.l(A,'z1',T) ) +
SUM((A,T)$DEPART('z1',A,T), CE('z1',A) * E.l('z1',A,T) ) +
SUM((A,T)$IDLETIME(A,T),   CB(A) * B.l(A,A,T) )  ;
NETREPORT('Tractor','Hours','3day','2a')  =  SUM((X,T,R), TT(X,'z1') * (OUT.l(X,T,R)
+ IN.l(X,T,R))) + SUM((A,T), TT('z1',A) * (E.l(A,'z1',T) + E.l('z1',A,T))) + SUM((A,T),
B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.1') = SUM((X,T,R)$DAY1(T), TT(X,'z1') *
 (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY1(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY1(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.2') = SUM((X,T,R)$DAY2(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY2(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY2(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.3') = SUM((X,T,R)$DAY3(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY3(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T)))+ SUM((A,T)$DAY3(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.4') = SUM((X,T,R)$DAY4(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY4(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY4(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.5') = SUM((X,T,R)$DAY5(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY5(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY5(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.6') = SUM((X,T,R)$DAY6(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY6(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY6(T), B.l(A,A,T)) ;
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NETREPORT('Tractor', 'Hours', '3day','2a.7') = SUM((X,T,R)$DAY7(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY7(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY7(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.8') = SUM((X,T,R)$DAY8(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY8(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY8(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.10') = SUM((X,T,R)$DAY10(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY10(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY10(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.11') = SUM((X,T,R)$DAY11(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY11(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY11(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.12') = SUM((X,T,R)$DAY12(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY12(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY12(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.13') = SUM((X,T,R)$DAY13(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY13(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY13(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.14') = SUM((X,T,R)$DAY14(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY14(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY14(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2a.15') = SUM((X,T,R)$DAY15(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,T)$DAY15(T), TT('z1',A) * (E.l(A,'z1',T) +
E.l('z1',A,T))) + SUM((A,T)$DAY15(T), B.l(A,A,T)) ;
* Alternative 2b ***
NETREPORT('Total','cost','3day','2b') = TOTALCOST.l -
SUM((A,X,T)$DEPART(A,X,T), CE(A,X) * B.l(A,X,T) ) ; NETREPORT('Tractor',
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'Hours','3day','2b') = SUM((X,T,R), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) +
SUM((A,X,T), TT(X,A) * E.l(X,A,T)) + SUM((A,T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.1') = SUM((X,T,R)$DAY1(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY1(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY1(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.2') =    SUM((X,T,R)$DAY2(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY2(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY2(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.3') = SUM((X,T,R)$DAY3(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY3(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY3(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.4') = SUM((X,T,R)$DAY4(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY4(T), TT(X,A) * E.l(X,A,T))
  + SUM((A,T)$DAY4(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.5') = SUM((X,T,R)$DAY5(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY5(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY5(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.6') = SUM((X,T,R)$DAY6(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY6(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY6(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.7') = SUM((X,T,R)$DAY7(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY7(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY7(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.8') = SUM((X,T,R)$DAY8(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY8(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY8(T), B.l(A,A,T)) ;
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NETREPORT('Tractor', 'Hours', '3day','2b.9') = SUM((X,T,R)$DAY9(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY9(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY9(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.10') = SUM((X,T,R)$DAY10(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY10(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY10(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.11') = SUM((X,T,R)$DAY11(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY11(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY11(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.12') = SUM((X,T,R)$DAY12(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY12(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY12(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.13') = SUM((X,T,R)$DAY13(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY13(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY13(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.14') = SUM((X,T,R)$DAY14(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY14(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY14(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2b.15') = SUM((X,T,R)$DAY15(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((A,X,T)$DAY15(T), TT(X,A) * E.l(X,A,T)) +
SUM((A,T)$DAY15(T), B.l(A,A,T)) ;
* Alternative 2c ***
NETREPORT('Total','cost','3day','2c') = TOTALCOST.l ; NETREPORT('Tractor',
'Hours', '3day','2c') = SUM((X,T,R), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) +
SUM((X,A,T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T), B.l(A,A,T)) ;
```

NETREPORT('Tractor', 'Hours', '3day','2c.1') = SUM((X,T,R)$DAY1(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY1(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY1(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.2') = SUM((X,T,R)$DAY2(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY2(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY2(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.3') = SUM((X,T,R)$DAY3(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY3(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY3(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.4') = SUM((X,T,R)$DAY4(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY4(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY4(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.5') = SUM((X,T,R)$DAY5(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY5(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY5(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.6') = SUM((X,T,R)$DAY6(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY6(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY6(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.7') = SUM((X,T,R)$DAY7(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY7(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY7(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.8') = SUM((X,T,R)$DAY8(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY8(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY8(T), B.l(A,A,T)) ;

NETREPORT('Tractor', 'Hours', '3day','2c.9') = SUM((X,T,R)$DAY9(T), TT(X,'z1') * (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY9(T), TT(A,X) * (B.l(A,X,T) + E.l(A,X,T))) + SUM((A,T)$DAY9(T), B.l(A,A,T)) ;

```
NETREPORT('Tractor', 'Hours', '3day','2c.10') = SUM((X,T,R)$DAY10(T), TT(X,'z1')
* (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY10(T), TT(A,X) * (B.l(A,X,T) +
E.l(A,X,T))) + SUM((A,T)$DAY10(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2c.11') = SUM((X,T,R)$DAY11(T), TT(X,'z1')
* (OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY11(T), TT(A,X) * (B.l(A,X,T) +
E.l(A,X,T))) + SUM((A,T)$DAY11(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2c.12') = SUM((X,T,R)$DAY12(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY12(T), TT(A,X) * (B.l(A,X,T) +
E.l(A,X,T))) + SUM((A,T)$DAY12(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2c.13') = SUM((X,T,R)$DAY13(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY13(T), TT(A,X) * (B.l(A,X,T) +
E.l(A,X,T))) + SUM((A,T)$DAY13(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2c.14') = SUM((X,T,R)$DAY14(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY14(T), TT(A,X) * (B.l(A,X,T) +
E.l(A,X,T))) + SUM((A,T)$DAY14(T), B.l(A,A,T)) ;
NETREPORT('Tractor', 'Hours', '3day','2c.15') = SUM((X,T,R)$DAY15(T), TT(X,'z1') *
(OUT.l(X,T,R) + IN.l(X,T,R))) + SUM((X,A,T)$DAY15(T), TT(A,X) * (B.l(A,X,T) +
E.l(A,X,T))) + SUM((A,T)$DAY15(T), B.l(A,A,T)) ;
NETREPORT('OUT',X,T,R)          = OUT.l(X,T,R) ;
NETREPORT('IN',X,T,R)           = IN.l(X,T,R) ;
NETREPORT('EMPTY',X,X1,T)       = E.l(X,X1,T) ;
NETREPORT('BOBTAIL',X,X1,T)     = B.l(X,X1,T) ;
NETREPORT('TRAILERS','STAY',X,T) = EE.l(X,T) ;
NETREPORT('DELIVERY','MARGINAL',X,R) = DELIVERY.M(X,R) ;
NETREPORT('PICKUP','MARGINAL',X,R)  = PICKUP.M(X,R) ;
DISPLAY
```

"LP Bound, 3 day service, bobtail cost = CE, DELIVERY, PICKUP, TRAILER, TRACTOR", NETREPORT ;

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